Proceedings of the Workshop on Rebuilding Techniques for Abalone in British Columbia

A. Campbell and L. D. Hiemstra (Editors)

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2003

PROCEEDINGS OF THE WORKSHOP ON REBUILDING TECHNIQUES FOR ABALONE IN BRITISH COLUMBIA

Edited by

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ABSTRACT

Campbell, A. and L. D. Hiemstra (Editors). 2003. Proceedings of the workshop on rebuilding techniques for abalone in British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 2482: 126 p.

An international Workshop on Rebuilding Techniques for Abalone in British Columbia was held at Nanaimo, British Columbia, Canada, 14-16 January 2003. The objective of the workshop was to examine past, present and future research on aquacultural, biological and ecological studies, which were relevant to future rebuilding efforts on northern (pinto) abalone, *Haliotis kamtschatkana*, stocks in British Columbia. The workshop was attended by 50 individuals representing First Nations, local communities, international (Australia, Canada, New Zealand, South Africa, and the U.S.A.) abalone research, management and aquaculture interests. Presentations and discussions at the workshop centred on community stewardship, enforcement, aquaculture, field research and rebuilding methods such as hatchery rearing, out-planting and restocking, wild stock manipulations, monitoring tools and evaluation performance indicators. There are four peer-reviewed papers and 13 abstracts in the Proceedings.

RÉSUMÉ

Campbell, A. and L. D. Hiemstra (Editors). 2003. Proceedings of the workshop on rebuilding techniques for abalone in British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 2482: 126 p.

Un atelier international sur les techniques de rétablissement des stocks d'ormeau de la Colombie-Britannique a eu lieu à Nanaimo, en Colombie-Britannique, du 14 au 16 janvier 2003. L'objectif de l'atelier était de passer en revue les résultats des études aquacoles, biologiques et écologiques passées et en cours et de cerner les recherches à mener à l'avenir dans ces domaines en vue du rétablissement des stocks d'ormeau nordique (*Haliotis kamtschatkana*) de la province. Les quelque 50 participants travaillant dans les domaines de la recherche, de la gestion et de l'aquaculture représentaient des Premières nations, des collectivités locales et la communauté internationale (Australie, Canada, Nouvelle-Zélande, Afrique du Sud et États-Unis). Les présentations et les discussions étaient centrées sur la gérance communautaire, l'application de la réglementation, l'aquaculture, la recherche sur le terrain et les techniques de rétablissement, comme la culture en écloserie, le repeuplement, la manipulation des stocks sauvages, les outils de surveillance et les indicateurs de la performance. Quatre articles évalués par des pairs et 13 résumés sont inclus dans les comptes rendus.

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PREFACE

Over exploitation and declines in wild abalone populations have occurred in many parts of the world. In British Columbia (BC), the decline of northern (pinto) abalone (*Haliotis kamtschatkana*) stocks since the late 1970s has prompted fishery closure since 1990, listing this species as "threatened" by the Committee on the Status of Endangered Wildlife in Canada in 1999, an international workshop (Campbell 2000) and development of a national recovery strategy for *H. kamtschatkana* in BC (Toole et al. 2002). Methods for successful rebuilding of wild abalone stocks are still in the developmental stage. Consequently, Fisheries and Oceans Canada Species at Risk hosted a workshop to discuss the challenges of developing methods to rebuilding abalone stocks in BC. This issue of the Canadian Technical Report of Fisheries and Aquatic Sciences contains the proceedings of the Workshop on Rebuilding Techniques for Abalone in British Columbia held at Nanaimo, BC, Canada, 14-16 January 2003. The workshop was attended by individuals representing First Nations, local communities, international (Australia, Canada, New Zealand, South Africa, and the U.S.A.) abalone research, management and aquaculture interests. The objective of the workshop was to examine past, present and future research on aquacultural, biological and ecological studies, which were relevant to future rebuilding efforts on northern abalone.

In the first two days of the workshop, discussions centred on current projects, reviews and perspectives on community stewardship, enforcement, aquaculture, field research and rehabilitation methods. On the third day, discussions were directed on different aspects of the abalone rebuilding methods appropriate for northern abalone management in BC: (1) Hatchery Rearing; (2) Out-planting and Restocking; (3) Wild Stock Manipulations; (4) Monitoring Tools and Evaluation Performance Indicators. See also Appendix 1 for the workshop agenda.

The workshop proceedings reflect the status of the many stages of knowledge on rebuilding methods for abalone populations. There are four full-length papers included in the proceedings. These papers were reviewed by at least two referees. Most presentations are represented by short or extended abstracts, some of which were also published as full papers in the primary literature (see Journal of Shellfish Research 22 (3), in press).

The workshop was a success, judging by the enthusiastic exchange of ideas and experiences and continuous discussions amongst the participants. The information provided from this workshop will to direct future rehabilitation efforts of depleted abalone stocks.

Alan Campbell
Workshop Chair

REFERENCES

Campbell, A. (Editor). 2000. Workshop on rebuilding abalone stocks in British Columbia. Can. Spec. Publ. Fish. Aquat. Sci. 130: 158 p.

Toole, J., B. Adkins, E. Bornhold, J. Boutillier, G. Caine, A. Campbell, A. Castledine, L. Convey, C. Cote, P. Coulson, T. Down, K. Francis, H. Gill, R. Harbo, H. Holmes, B. Jubinville, D. Lawseth, B. G. Lucas, A. Morgan, G. Parker & J. Rogers. 2002. National Recovery Strategy for the Northern Abalone (*Haliotis kamtschatkana*) in British Columbia. Fisheries and Oceans Canada. (http://www-comm.pac.dfo-mpo.gc.ca/pages/consultations/fisheriesmgmt/abalone/AbaloneRecovStrategy_e.htm). 22 p.

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INTRODUCTORY REMARKS

INTRODUCTION AND OVERVIEW

by

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On behalf of Fisheries and Oceans Canada (DFO), I welcome you all to Nanaimo. Thank you for participating in the Workshop on Rebuilding Techniques for Abalone in British Columbia BC.

This workshop brings together a diverse group of individuals who are working on different aspects of abalone. Many of you are from coastal communities, representing First Nations, business and aquaculture. There are also participants representing research institutes and government organisations from within Canada and abroad, from as far away as Washington State, California, Australia, New Zealand and South Africa.

Many countries of the world, including Canada, Japan, South Africa and the United States of America, have documented reductions in several abalone species. While these countries have taken steps to limit harvest, abalone populations continue to decline. This workshop will provide the participants an opportunity to share scientific, technical and traditional knowledge from a number of jurisdictions and perspectives and to discuss the challenges of developing methods to rebuild abalone stocks, an important and culturally significant natural resource in B.C.

The northern or pinto abalone (*Haliotis kamtschatkana*), once an abundant abalone species in coastal areas of B.C., has been a traditional food of First Nations, a prize for recreational divers, and the object of a small but economically important commercial dive fishery during the 1970s and 1980s. In response to observations of population declines, as documented by regular surveys since the late 1970s, all B.C.'s abalone fisheries were closed to harvest in 1990. Since this closure, surveys have indicated no evidence of stock rebuilding. A workshop on rebuilding abalone stocks in B.C. was held in Nanaimo, during February 1999, and initiated a number of activities to rehabilitate depleted northern abalone stocks in B.C. The proceedings of this workshop were published (Campbell 2000). In April 1999, B.C.'s northern abalone population was designated *threatened* by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Subsequently, a National Recovery Strategy for Northern Abalone in B.C. was developed and has recently been approved in November, 2002 by the Minister of Fisheries and Oceans Canada. This is the first marine mollusc in Canada to be designated as *threatened* and to have a National Recovery Strategy approved, which will be mandatory under the new *Species at Risk Act* (SARA).

Speaking of the *Species at Risk Act* (SARA), you may or may not know that the *Act* has received Royal Assent on December 12th, 2002 and should be proclaimed by the Canadian Parliament by next summer. The overall goal of the *Species at Risk Act* is to prevent wildlife species from becoming extinct or lost from the wild, and to help in the recovery of species that are at risk as a result of human activities. The Act builds on existing laws and programs, such as the *Fisheries Act*, the *Migratory Birds Convention Act*, the *National Parks Act*, as well as provincial and territorial legislation and programs.

This new *Act* will create many new obligations for DFO, going from participation in the assessment of species and identification of critical habitat to the development and implementation of recovery strategies in partnership with various stakeholders. This new *Act* will impact on the overall management of aquatic resources and their habitat.

Coming back to the workshop, the objectives are to examine past, present and future research on aquacultural, biological and ecological studies that are relevant to future rebuilding efforts on northern abalone in B.C. A number of groups, including First Nations and coastal communities, university, governmental and non-governmental organisations have already begun activities to remove abalone from the threatened list. We need to better understand the biology and population ecology of northern abalone, and to continue to collaborate on research, enforcement, aquaculture, enhancement and community involvement to improve the rebuilding techniques currently being used, and to discover the possible new directions that are required in our rebuilding efforts.

During the first two days, the workshop will provide an update and review of abalone rebuilding efforts currently underway in B.C. and with other abalone species in different parts of the world. The third and final day of the workshop is structured for working groups to provide suggestions to direct future rebuilding efforts. The recommendations provided from this workshop will be reviewed critically by Fisheries and Oceans Canada to improve the rebuilding techniques wherever possible that are being implemented to recover the northern abalone population in B.C.

On behalf of DFO, I hope that your discussions are productive and enjoyable during the next few days and that the ideas generated by this workshop will help direct our efforts into removing the abalone from the threatened species list.

REFERENCES

Campbell, A. (Editor). 2000. Workshop on rebuilding abalone stocks in British Columbia. Can. Spec. Publ. Fish. Aquat. Sci. 130: 158 p.

STATUS OF STEWARDSHIP PROJECTS

ABALONE STEWARDSHIP IN HAIDA GWAII: FORGING A LONG-TERM COMMITMENT

by

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ABSTRACT

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Local stewardship is a possible solution to the vexing problem of rebuilding over fished northern abalone (*Haliotis kamtschatkana*) stocks. Abalone fisheries in British Columbia were closed coastwide in 1990 but stocks have failed to rebuild and the species became federally listed as "threatened" in 1999. We describe three years of community-based stewardship effort in Haida Gwaii to rebuild abalone and prospects for recovery over the long-term. Steps taken include forging a community partnership through regular meetings of a core group and development of a Community Action Plan. The Action Plan's goal is to rebuild abalone populations sufficiently to support both Haida traditional and recreational food fisheries. Specific initiatives include public education, curricula development, establishment of two large abalone stewardship areas and a research area, creation of an Abalone Watch (coastal surveillance) program and research diving to test rebuilding approaches and monitor recovery. The community response has been positive, but it is too soon to confirm whether there have been changes in human attitude and increases in abalone populations. The challenge is to maintain community interest and commitment over the long-term to allow results to be manifested. Much will depend on setting achievable stock rebuilding reference points both for the stewardship areas and Haida Gwaii. As well, the prospect of the return of the sea otter (also listed as a "threatened" species) that is a keystone species in the kelp forest ecosystem and a predator of northern abalone could result in reduced abalone abundance despite stewardship efforts.

Key words: abalone, stewardship, *Haliotis kamtschatkana*, recovery plan

INTRODUCTION

Northern or pinto abalone (*Haliotis kamtschatkana*) stocks in Haida Gwaii (Queen Charlotte Islands), British Columbia (B.C.) (Fig. 1), remain at low levels despite all fisheries having been closed since 1990. Community stewardship is a possible solution to stock rebuilding and local organisations on Haida Gwaii are collaborating to achieve this. We describe three years of broad community-based actions by a local stewardship group, the Haida Gwaii Abalone Stewards. While results have been encouraging in the public outreach component, it is too early to confirm increases in abalone populations.

The stewardship group involves the Haida Nation, three non-governmental organisations and three federal agencies. Haida Fisheries Program (HFP) manages fisheries research for the Council of the Haida Nation and works co-operatively with Fisheries and Oceans Canada (DFO) scientists. HFP has had an active research dive program since 1992. Laskeek Bay Conservation Society, Haida Gwaii Marine Resource Group Association (HGMRGA) and World Wildlife Fund-Canada are local and national NGOs with marine environmental mandates. Laskeek Bay Conservation Society has operated a broad marine and terrestrial research program focused on ancient murrelet from their field station at Limestone Island since 1990. HGMRGA, comprised of community and fisheries representatives, formed in 1998 to administer Fisheries Renewal BC funding for salmon and DFO habitat stewardship activities. The local office of World Wildlife Fund Canada focuses on marine area conservation and protected area initiatives. The three federal government partners include Parks Canada Agency (mandated under the *Canada National Parks Act*) which co-manages with the Council of the Haida Nation the 1,500 km^2 terrestrial park Gwaii Haanas National Park Reserve and Haida Heritage Site. Other agencies include DFO that is responsible for abalone research and management under the *Fisheries Act* including area closure and enforcement functions. Environment Canada, Parks Canada Agency and DFO share responsibilities (with Environment Canada in the lead) for implementing the *Species at Risk Act* (passed 2002) that oversees protection and recovery of species federally listed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). Environment Canada administers the Habitat Stewardship Program that is providing interim funding for initiatives related to this new legislation.

BACKGROUND

Northern abalone in B.C. have been closed to all fishing since 1990 due to low populations (Campbell 2000, Toole et al. 2002). There has been no recovery and abalone was listed as "threatened" by COSEWIC in 1999 (http://www.cosewic.gc.ca). Threatened means populations are expected to continue to decline unless limiting factors are reversed. Abalone are slow growing and relatively long-lived with low or sporadic recruitment. They are usually found on exposed rocky coasts associated with kelp forests from the lower intertidal to <12m depth and are, therefore, susceptible to overexploitation. The main causes of continuing low stock levels are illegal harvest and low recruitment (Toole et al. 2002). Other possible factors are disease or interactions with predators/competitors, although there is little evidence that these are major contributors in Haida Gwaii. COSEWIC identified the major threats to abalone as illegal harvest and sea otters where they occur.

Abalone have been plentiful in Haida Gwaii and were fished by the Haida possibly for millennia (Sloan et al. 2001). Abalone densities were likely much lower two hundred years ago due to the presence of sea otters (see discussion later). Sea urchins were was also once rare to find and were hence highly valued by the Haida (Diane Brown, personal communication). The Haida traditionally gathered abalone by hand-picking at low tide or with a two-pronged seafood spear deployed from canoes or boats. Abalone were also dried and sometimes traded. There were attempts to start a small commercial fishery in the early 1900s (Sloan et al. 2001). Commercial and recreational fisheries expanded in the 1960s and 1970s with the advent of SCUBA gear. Pacific Fisheries Management (PFM) Areas 2E and 1 were major production areas during the commercial fishery accounting for 31% and 9% of B.C. commercial landings from 1977 to 1990 (Table 1). Landings in PFM Area 2E were highest in the first few years of the fishery but declined as coast-wide quotas (first set in 1979 at 227 t) were continuously reduced (to 47.2 t by 1985). Although catch was limited with a quota, the actual take was higher as illegal fishing was likely substantial (Campbell 2000).

DFO has conducted regular abalone abundance surveys at index sites in several areas of B.C. including PFM Area 2E (Campbell et al. 2000). Figure 2 shows the change in mean density (abalone/m^2) of legal-sized ($\geq$ 100 mm shell length, SL) adult abalone in PFM Area 2E from 1978 to 1998 (1998 results = 0.088 $\pm$ 0.022 SE). Another survey was done in 2001 but results were not yet available from DFO. Estimates have large confidence limits which make it difficult to detect changes, particularly at low levels. This dataset has been used to assess population decline by DFO and determine population status for COSEWIC and is also the only long term dataset for assessing recovery in Haida Gwaii. Recent population trends are unclear from these surveys (Campbell 2000). Densities of all abalone increased from 1994 to 1998 (0.33 to 0.53 abalone/m^2) and the number of sites with no abalone was relatively unchanged in 1998 (at 7% after fluctuating between 5 and 16% from 1987 to 1998). But the number of sites with no legal-sized abalone (SL $\geq$ 100 mm SL) increased in 1998 to 70% from 25% in 1978 and a range of 46 to 59% in the 1984 to 1994 surveys.

DECIDING TO GET INVOLVED

The closure of abalone fisheries in 1990 was unpopular with many Island residents who felt victimised by a closure they did not cause as few commercial abalone licence holders lived in the communities where abalone were fished. HFP developed a dive team in the early 1990s to assess invertebrate stocks and participated in most local DFO abalone index surveys since then. In 1998 and 1999, HFP conducted abalone surveys in Area 1 in collaboration with DFO. In 2000, HFP and community partners obtained Habitat Stewardship Program funding to lead further dive surveys in PFM Area 2E and initiate public outreach. In February 2001, community workshops were held with invited speakers on abalone stock status, local cultural values and rebuilding abalone in California. Citizens articulated local abalone issues and discussed possible actions. Haida people talked about the importance of abalone for food gathering and the possibility of never again being able to legally take abalone. Some workshop participants blamed commercial fishers and DFO management for declines while others believed that there is still enough abalone for food fisheries. A key conclusion of the workshops was that there was a need for community action to ensure that abalone would be there for future generations of Islanders.

A COMMUNITY ACTION PLAN

As a result of the community workshops, a local working group made up of representatives of the stewardship groups was struck to develop a Community Action Plan to articulate goals and strategies for rebuilding abalone. The action plan described the issues and laid out a strategy for abalone rebuilding including public education, school curricula development, establishment of two large abalone stewardship areas as a focus for rebuilding efforts, creation of an Abalone Watch (coastal surveillance) program and research diving to test rebuilding approaches and monitor recovery. The goal of the action plan is to rebuild populations to levels that will once again support both Haida traditional and recreational food fisheries. This differs from DFO's abalone recovery strategy more short-term goal of stopping population decline (Toole et al. 2002).

A public process was followed to review and approve the plan. A draft plan was widely circulated in February 2002 with 1,500 copies distributed in the local newspaper and mailed to several commercial shellfish fishery associations that did not have offices in Haida Gwaii. Feedback was solicited through questionnaires and two public meetings. There were also several presentations to Haida and school audiences. The response rate to questionnaires was low (40 returned including 16 from schools). A final plan draft was completed in April 2002 and a decision was made to seek endorsement of the plan by community partners (including federal government departments). The plan is still in the process of being endorsed by partners. The action plan has been an important tool for focusing community efforts and serves as a document that can be publicly supported by community organisations. The action plan is not legally binding and relies largely on voluntary community support to be successful.

Following is a description of activities and progress to date on key elements of the plan:

Local working group

The local working group is made up of about nine persons representing the partner groups. In addition to developing the Community Action Plan, this group plans and co-ordinates local events and participated in review of DFO abalone recovery plans. Community members have taken the lead on most issues with agency members providing support as needed.

Outreach and education

These activities focus on improving public awareness and education about abalone conservation. Materials developed include fact sheets on abalone biology and conservation, a poster, and a brochure targeting visitors to Haida Gwaii. A key targeted group has been school-age children. A curriculum unit was developed for grades 4-7 that uses lessons, games, and hands-on display items such as abalone shells and a sea otter pelt. It is being further tested and developed in 2002-03. Since many children have never seen a live abalone, a video was made of abalone *in situ*. Activities targeted at the local community included presentations by invited speakers on abalone life history, sea otters and marine protected areas. As well, booths were sponsored, during major annual community events, which included exhibits such as intertidal touch-tanks for children. Also, presentations were directed at fishing industry groups whose members may encounter abalone when fishing in Haida Gwaii such as the Pacific Urchin Harvesters Association and the Herring Industry Advisory Board.

Stewardship Areas

Two stewardship areas, North Coast Graham Island and Juan Perez Sound, were identified as a focus for stewardship efforts (Fig. 1). Stewardship areas were selected because they possessed good abalone habitat, have supported historic fisheries, and still have abalone populations. Using historic fishery-dependant and –independent data are important in selecting areas for abalone research and restoration (Rogers-Bennett et al. 2002). As well there are ongoing activities and infrastructure in these areas that can be used for monitoring of the area and protection of abalone stocks (Fig. 1). HFP operates two watchmen camps at North Graham Island in the vicinity of Naden Harbour and Langara Island from May to September to monitor recreational fisheries in the area. The Skidegate Band Council operates watchmen camps in Juan Perez Sound at Hotsprings Island and Windy Bay during the same period as part of management of Gwaii Haanas. Old Massett Village Council operates a Rediscovery youth camp at Lepas Bay at North Graham Island during the summer months. In addition, we have sought formal designation of the northern portion of Juan Perez Sound as an area for experimental research and closure to the commercial red sea urchin fishery. In the fall of 2002 a meeting was held with DFO and dive industry representatives that resulted in the area being closed to the red urchin fishery in the current management cycle. A formal closure is expected to be included in the next management plan that begins in July 2003.

There was considerable discussion about the location of the proposed stewardship areas. Portions of both areas were closed to the commercial abalone fishery in the 1970s to provide for recreational and Haida food fisheries. However these areas were depleted along with areas open to commercial fisheries. Smaller areas were initially proposed for the stewardship areas but public comments proposed enlarging them to their present size. Stewardship areas have no formal regulatory status but act as a focal point for stewardships efforts as well as providing a means to monitor the effects of these efforts. Rebuilding is expected to occur faster in stewardship areas than the general area due to reductions in illegal harvests.

Abalone Watch

Activities in the Abalone Watch program mainly involve volunteers helping to protect abalone. The program is still at an early stage of development and is modelled on the Coastwatch program that aims at detecting illegal immigration or drug smuggling coast-wide. Activities so far have focused on identifying what we want people to do, the type of information they need to look for and how to do this safely. A local HFP/DFO committee was established to review enforcement priorities and co-ordinate joint activities such as underwater enforcement checks of commercial divers and aeroplane and boat surveillance. A reporting form was developed for use by HFP Watchmen and other Abalone Watch volunteers. The ultimate aim of the program is to establish a network of vessels or stations that will observe, record and report on local traffic and suspicious activities in order to detect illegal abalone harvesting. The majority of activities would take advantage of vessels and people already on the water although some additional patrols are expected in stewardship areas during times when volunteer activities are minimal.

LOCAL RESEARCH AND MONITORING

HFP has conducted abalone dive surveys in the stewardship areas since 1998 using survey designs developed in consultation with DFO. As information becomes available on the results of surveys, updates are provided to the general public through newsletters and presentations. Activities include:

Reconnaissance Surveys

These were conducted in both stewardship areas to provide baseline data on abalone habitat, distribution and abundance using various survey protocols (Table 2). In the North Graham Island area, a series of dive surveys were conducted in four areas over three years: surveys during 1998 used "Breen survey" methods as applied in DFO index site surveys (Breen and Adkins 1979) except at randomly selected locations instead of known beds; surveys during 1999 and 2000 used timed swims parallel to shore. In 1999, sites were randomly selected and dives collected data on habitat as well as abalone abundance. In 2000, locations were systematically selected along the shoreline but searches were shorter (approximately 12 minutes per dive ranging from 3-18 minutes) and focused in the general area on sites with good habitat (hard substrate along the margin of the kelp canopy). An important result of the 1998 survey was finding lower abalone densities in Area 1 (0.25 abalone/m^2) compared to DFO index surveys in PFM Area 2E in 1998 (0.49 abalone/m^2, Campbell et al. 2000). The switch in 1999 from "Breen surveys" to timed swims gave comparative measures of abundance between sites while allowing more sites to be examined in a day. In Juan Perez Sound, surveys were conducted in six areas over two years: surveys during 2000 used timed swims targeted at good abalone habitat and surveys during 2001 were transects with systematic sampling of 1 m^2 quadrats. Surveys during 2001 were done co-operatively with DFO. Survey information in Juan Perez Sound was used to identify a research area and select experimental and control plots in Juan Perez Sound.

Adult Density Manipulation

An experiment is underway in the upper Juan Perez Sound research area to investigate the feasibility of artificially aggregating abalone at high densities as a means of enhancing abalone reproduction. Adult spawning density and patch size have been proposed as possible limiting factors for successful fertilisation of gametes and reproduction (Campbell 1997). In 2002, we established 8 treatment and 8 control plots at sites in upper Juan Perez Sound. Mature abalone densities (≥ 50 mm) in 10 m x 10 m treatment plots were increased from 0.2 to 1.7 mature abalone·m^{-2}. Preliminary results indicated some dispersal of abalone soon after transplanting. The experiment will be completed in 2003.

Juvenile Collectors

Thirty-two artificial concrete block habitats, designed to monitor abundance and size of cryptic juvenile abalone, were deployed in clusters of 4 at 8 sites during July 2001 (DeFreitas 2003). Two additional sites were established in 2002. Each habitat or "collector" provides about 3.5 m^2 of habitat and consists of 24 concrete mini-blocks randomly arranged within a modified commercial crab trap. Juveniles were difficult to find in significant numbers in typical surveys. Preliminary results from the surveys conducted during 2002 indicated that juvenile abalone occupied the collectors in sufficient numbers to detect differences in abundance between sites. Whether there will be a significant correlation with juvenile abalone occupying the surrounding natural habitat is uncertain.

Tagging

A total of 1,695 abalone was tagged at three long-term monitoring sites in the stewardship areas to provide information on growth and mortality rates. Two sites were established in 1998 and the third in 2000. These locations are revisited 2-4 times annually and provide information on abalone growth rates within specific habitats. Estimates of natural mortality are expected based upon the seasonal collection of tagged abalone shells.

DISCUSSION

We have taken a variety of approaches to abalone conservation and rebuilding in Haida Gwaii. This stems from uncertainty about why abalone populations have failed to respond to the 1990 fishery closure. Table 3 shows the main stewardship activities and their applicability to addressing illegal harvest and low recruitment, the two major current issues affecting abalone recovery in Haida Gwaii.

Three of the stewardship activities, establishment of stewardship and research areas, outreach and education and Abalone Watch are expected to reduce illegal fishing over the long-term (Table 3). Publicity about surveillance and enforcement in the stewardship areas are expected to deter poaching. If it is assumed that illegal fishing was a major factor contributing to declines, then stewardship areas should aid recovery more quickly than in other areas. This creates an opportunity for monitoring rebuilding in stewardship areas without the confounding factor of illegal harvest, or at least with a reduced effect.

Other stewardship activities such as juvenile monitoring and adult aggregation experiments in the stewardship areas are expected to provide information about abalone recruitment (Table 3). We hope that juvenile collectors will provide estimates of recruitment more efficiently than survey data. Experiments involving adult aggregation are testing whether artificially aggregated adult abalone will stay aggregated with potential benefits for reproduction. If successful, aggregations are expected to contribute on a small scale to improving recruitment rates. Further, the techniques could be applied on a larger scale to improve reproductive success. In order for these investigations to be successful, it is important that no illegal fishing occur at experimental sites that would not be possible without the stewardship areas.

Stewardship activities provide an alternative approach to the issue of illegal fishing. DFO believes illegal fishing to be significant and that traditional enforcement failed to deter poaching either before or after the 1990 closure (Anon. 2002). Abalone watch does not replace the need for traditional enforcement but recognises that "a bigger stick" is not the only answer to illegal fishing. Stewardship activities allow organisations other than DFO to deliver the conservation message to the public and draw on peer pressure to deter illegal fishing, particularly in small communities where people are likely to know each other. Introduction of the Abalone Watch network increases the risk of poachers being caught as every boat on the water could potentially be participating in a voluntary observe, record and report program. During workshops several persons described anecdotes about large scale illegal harvesting. Presentations to the public emphasise the importance of reporting suspected illegal activities to enforcement authorities in a timely manner.

Dive surveys have been an important aspect of stewardship activities providing data on distribution and abundance at smaller spatial scales than DFO index surveys. Frequent informal reports have helped to generate community interest in abalone, a species that is out of sight of most people. Another important aspect of HFP surveys is that they are independent of DFO stock status surveys, although they have provided complementary data. This has countered claims by some that abalone populations are already rebuilt or have not declined from historic levels.

Aquaculture is a potential rebuilding technique that is being investigated by other groups in B.C. but has not been assessed for Haida Gwaii. Abalone aquaculture has not been a priority for our group due to the presence of significant although depressed abalone populations (at approximately 10-20% of historic levels) and the extensive area that would be involved if this technique were to be applied in Haida Gwaii. Techniques could be applied in Haida Gwaii if field trials in other regions prove successful.

There are several critical issues that will affect the success of stewardship efforts over the long-term. These are the timeframe for reopening abalone fisheries and the arrival of sea otters to the islands after an absence of approximately 100 years.

There are currently no DFO rebuilding targets although DFO estimates that rebuilding may require several decades (Anon. 2002, p. 10). One of the suggested criteria for reopening the abalone fishery is to wait until abundance indices of spawners and recruits reach 50% of "virgin" stock biomass as seen in the 1970s (Campbell 1997). However, Campbell (1997) also acknowledged that reopening criteria should also depend on the management objectives and type of future fishery including target yield. In Canada, First Nations' food, social and ceremonial fisheries have a legal priority over commercial and recreational fisheries. This has led to different target escapements or reference points for opening First Nation and commercial or recreational sockeye salmon fisheries on the Skeena River (Anon. 2002). This recognizes that objectives for conservation and rebuilding of stocks may differ and that relatively small First Nations takes are sustainable at a lower stock level than other takes. For instance a harvest of several hundred kilograms per year would have a smaller impact than harvests of tonnes. After all populations in PFM Area 2E (Fig. 2) remained at low levels but relatively stable from1984 to 1990 despite abalone removals of close to 12 tonnes/year (Table 1). If stocks rebuild it is expected that First Nations' fisheries would open first in order to reflect its' legal priority over commercial and recreational fishing.

The type of fishing methods allowed may also affect reopening criteria. For instance traditional Haida take of abalone involved hand-picking at low tide or spearing from a vessel that limits catching to depths of approximately 2 m. Fishing in this manner leaves a depth refuge for abalone and would be more precautionary than fishing by SCUBA.

Another important factor affecting the long-term outlook for abalone in Haida Gwaii is the imminent arrival of sea otter. There have been six confirmed observations of sea otters in southern Haida Gwaii since 1972, although none were in or near the stewardship areas. Anecdotal information indicates that sea otters also occur as little as 70 km away albeit over open water at Prince of Wales Island in Alaska, and further away in the Goose Island Group on the central coast of B.C. On the west coast of Vancouver Island foraging sea otters reduced abalone to crevices and concentrate animals in refugial habitats to $< .05$ abalone/m^2 (Watson 2000). In Haida Gwaii, >80% of abalone are found to be exposed so that sea otter predation would result in reductions of at least this magnitude. Watson also observed that removal of invertebrate herbivores by sea otters led to increases in algal abundance and speculates that this would benefit abalone by providing increased cover and drift algae availability and possibly improving larval entrainment and settlement.

Sea otters and abalone are known to have had a long evolutionary coexistence although abalone were once probably relatively rare. Campbell (2000) speculates that there should be no expectation of reopening an abalone fishery in areas that have or are predicted to have sea otter populations within perhaps 10 to 20 years. This raises questions about the purpose of rebuilding abalone populations if their numbers could be reduced to low levels with the arrival of greater numbers of sea otters in some areas. If abalone populations in crevice habitat are small but self-sustaining in other parts of the coast in the presence of sea otters (and Haida Gwaii prior to their local extinction), then some human exploitation, should be possible now prior to the arrival of sea otter, by traditional methods that provide a depth refuge similar to the historical situation. In any case, the development of sea otter and abalone recovery plans need to be integrated to account for interrelationships between these two species. If rebuilding takes several decades and extends beyond the arrival of sea otter, then it will create challenges for maintaining community interest and commitment in abalone stewardship.

Stewardship is a fresh approach to conservation and rebuilding of abalone stocks in Haida Gwaii that addresses critical human and biological factors including illegal harvest and low recruitment. Stewardship must however be recognized as a long term venture requiring nurturing and commitment from both the community and government. It takes time to build support and change attitudes. Also abalone populations may not respond for some time, and may take decades to rebuild to historical levels. If this is so, community support for fishing closures may dwindle. To nurture this support it is important to maintain hope for small-scale takes and establish reference points at which they could occur. As a future step, we recommend that rebuilding goals be developed in consultation with the community as well as options for accessing stocks that have sufficiently rebuilt. This is likely a critical point in terms of abalone recovery in Haida Gwaii, as populations have failed to show signs of rebuilding but are not endangered. Our success is likely to depend on how we address human factors necessary for abalone recovery as well as difficult policy issues such as conservation thresholds and the prospect of sea otters returns.

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REFERENCES

Anonymous 2002. Pacific Region Integrated Fisheries Management Plan Salmon Northern B.C. April 1, 2002 to March 31, 2003. Fisheries and Oceans Canada, Pacific Region. 82 p. [http://www.pac.dfo-mpo.gc.ca/ops/fm/mplans/plans02/NSalmon02pl.PDF]

Breen, P.A. and B.E. Adkins. 1979. A survey of abalone populations on the east coast of the Queen Charlotte Islands, August 1978. Fish. Mar. Serv. Manuscr. Rep. 1490: 125 p.

Brown, Diane. 2002. Personal communication, December 2002. Instructor for the Skidegate Haida Immersion Program and member of the Skidegate Haida Language Authority, Skidegate, B.C.

Campbell, A. 1997. Possible criteria for reopening the Northern abalone (*Haliotis kamtschatkana*) fishery in British Columbia. DFO Can. Stock Assess. Sec. Doc. 97/64. 47 p.

Campbell, A. 2000. Review of northern abalone, *Haliotis kamtschatkana*, stock status in British Columbia. Can. Spec. Publ. Fish. Aquat. Sci. 130: 41-50.

Campbell, A., D. Brower, J. Rogers, and D.C. Millar. 2000. Abalone resurvey in southeast Queen Charlotte Islands, 1998. Can. Manuscr. Rep. Fish. Aquat. Sci. 2528: 30 p.

DeFreitas, B. 2003. Estimating juvenile northern abalone, *Haliotis kamtschatkana*, abundance using artificial habitats. J. Shellfish Res. 22 (3) (in press).

Harbo, R. 1997. Abalone dive fishery (Closed). Can. Manuscr. Rep. Fish. Aquat. Sci. 2369: 86-92.

Rogers-Bennett, L., P.L. Haaker, K.A. Karpov, and D.J. Kushner. 2002. Using spatially explicit data to evaluate marine protected areas for abalone in Southern California. Conservation Biology 16: 1308-1317.

Sloan, N.A., P.M. Bartier, and W.C. Austin. 2001. Living marine legacy of Gwaii Haanas. II: Marine invertebrate baseline to 2000 and invertebrate-related management issues. Parks Canada Technical Reports in Ecosystem Science 35: 331 p.

Toole, J., B. Adkins, E. Bornhold, J. Boutillier, G. Caine, A. Campbell, A. Castledine, L. Convey, C. Cote, P. Coulson, T. Down, K. Francis, H. Gill, R. Harbo, H. Holmes, B. Jubinville, D. Lawseth, B. Lucas, A. Morgan, G. Parker, and J. Rogers. 2002. National Recovery Strategy for the Northern Abalone (*Haliotis kamtschatkana*) in British Columbia. Fisheries and Oceans Canada. 22 p. [http://www-comm.pac.dfo-mpo.gc.ca/pages/consultations/fisheriesmgmt/abalone/AbaloneRecovStrategy_e.htm].

Watson, J. 2000. The effects of sea otters (*Enhydra lutris*) on abalone (*Haliotis* spp.) populations. Can. Spec. Publ. Fish. Aquat. Sci. 130: 123-132.

Wells, S. and A.T. White. 1995. Involving the community, p. 61-84. In Susan Gubbay [ed.]. Marine Protected Areas: principles and techniques for management. Chapman & Hall, London.

Table 1. Haida Gwaii abalone landings by DFO Pacific Fishery Management area, 1977-90 from harvest logs (Harbo 1997).

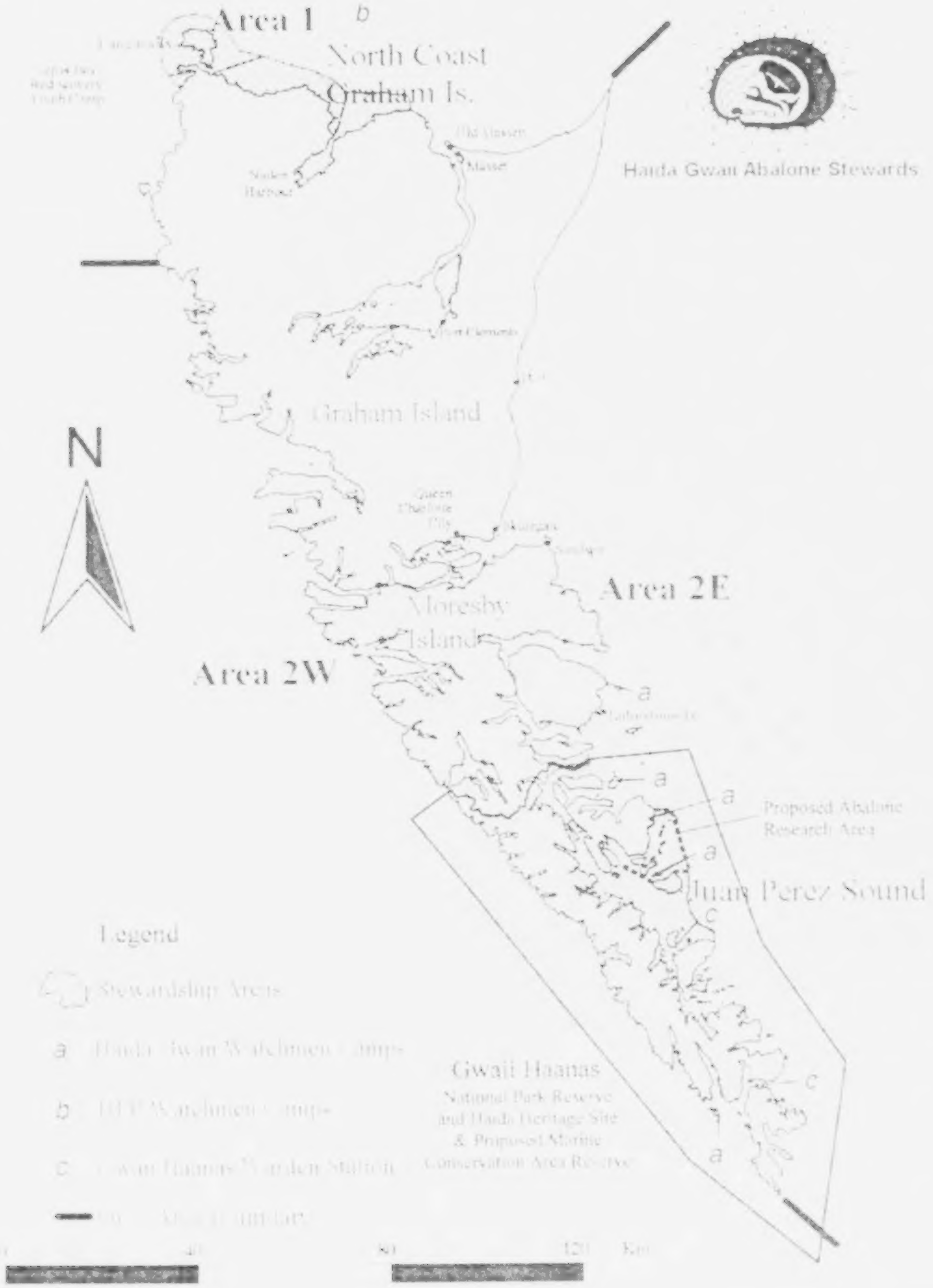
Year	Landings (t)			
	Area 1	Area 2E	Area 2W	B.C.
1977	45.5	259.5	13.6	481
1978	12.9	101.2	14.6	404
1979	2.6	29.5	5.7	209
1980	3.2	16.2	3.7	105
1981	1.9	21.3	6.1	94
1982	13.0	13.6	0.2	82
1983	12.1	20.3	0.0	55
1984	14.2	14.0	0.9	58
1985	9.6	4.4	0.0	45
1986	15.3	6.5	2.1	46
1987	4.5	14.3	3.1	46
1988	8.1	19.1	1.4	47
1989	5.3	11.3	3.2	47
1990	5.9	12.2	0.6	47
Total (1977-90)	154	543	55	1766
% of B.C. landings	8.7%	30.7%	3.1%	100.0%
Annual Average (1984-90)	11.7	9.0	1.9	48.0

Table 2. Baseline reconnaissance surveys in abalone stewardship areas (results are not comparable since survey areas differed and methods varied).

Year	Location	Survey Methods	Survey Length/ Dive time	Sites		Total abalone found (number)	Abalone density or encounter rate
				Total	Number without abalone		
1998	NW Graham Is. 3.7 km	Breen survey, random selection	10 d	63	17	1,008	0.25 / m^2
1999	NW Graham Is. 9.0 km	Timed dives, random selection	6 d/ 1362 min	21	5	518	0.38 / min
2000	N Juan Perez Sound 6 areas	Timed dives, targeted good abalone habitat	11 d/ 1653 min	135	10	7,148	4.32 / min
2000	NW Graham Is. 2 areas	Timed dives, targeted good abalone habitat	2 d/ 131 min	15	6	205	1.56 / min
2001	N Juan Perez Sound 4 areas	Transects/ quadrats, targeted good abalone habitat	8 d	51	3	280	0.32 / m^2

Table 3. Applicability of Haida Gwaii stewardship activities to major issues thought to contribute to abalone declines.

Stewardship Activity	**Abalone Rebuilding Issues**	
	Illegal Harvest	**Low Recruitment**
Stewardship and research areas	Yes	Yes
Education	Yes	No
Abalone Watch	Yes	No
Juvenile collectors	No	Yes
Adult aggregation	No	Yes


Area 1
b
North Coast
Graham Is.
Naden Harbour
Old Massett
Masset
Port Clements
Graham Island
Haida Gwaii Abalone Stewards
N
Queen Charlotte City
Skidegate
Sandspit
Area 2E
Moresby Island
Area 2W
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a
a
Proposed Abalone Research Area
a
Juan Perez Sound
c
c
a
Legend
Stewardship Areas
a Haida Gwaii Watchmen Camps
b Watchmen Camps
c Gwaii Haanas Warden Stations
Area Boundary
Gwaii Haanas
National Park Reserve
and Haida Heritage Site
& Proposed Marine
Conservation Area Reserve
0
40
80
120
Km

Figure 5: Haida Gwaii Abalone Stewardship Areas

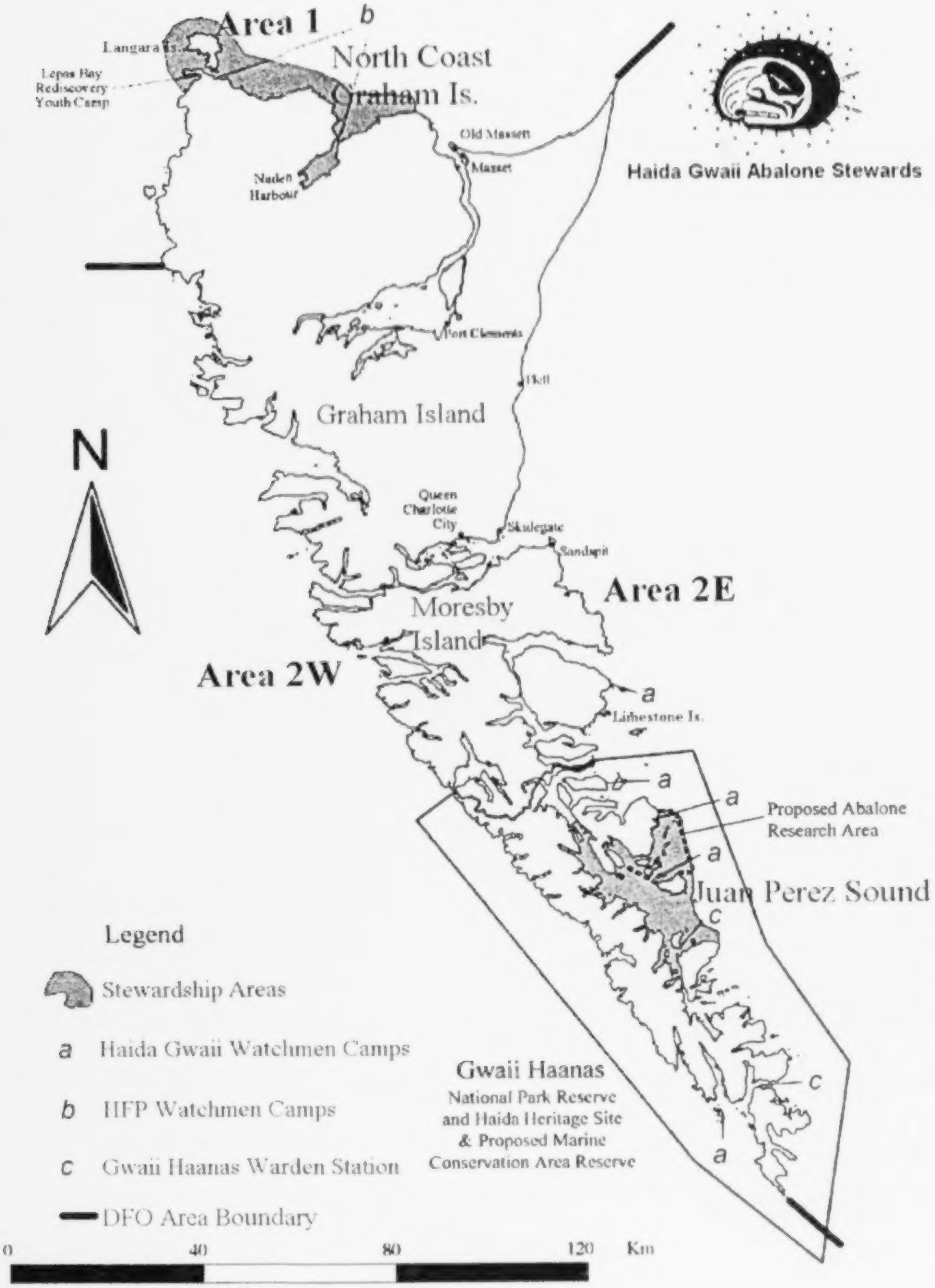
Area 1
b
Langara Is.
Lepas Bay Rediscovery Youth Camp
North Coast Graham Is.
Old Massett
Masset
Naden Harbour
Haida Gwaii Abalone Stewards
Port Clements
Tlell
Graham Island
N
Queen Charlotte City
Skidegate
Sandspit
Area 2E
Moresby Island
Area 2W
a
Limestone Is.
a
a
Proposed Abalone Research Area
a
Juan Perez Sound
c
Legend
Stewardship Areas
a Haida Gwaii Watchmen Camps
b HFP Watchmen Camps
c Gwaii Haanas Warden Station
DFO Area Boundary
Gwaii Haanas
National Park Reserve and Haida Heritage Site & Proposed Marine Conservation Area Reserve
c
a
0
40
80
120
Km

Figure 1. Haida Gwaii Abalone Stewardship Areas.

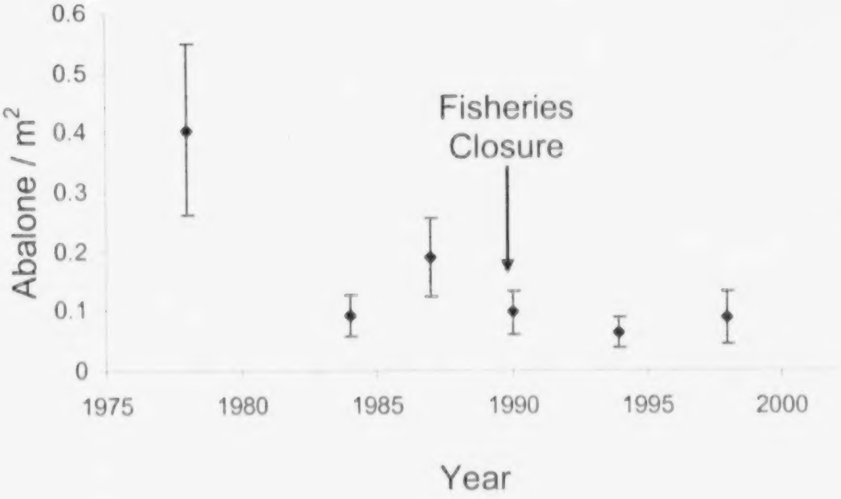

Figure 2. Mean density of legal (≥ 100 mm SL) abalone from surveys in PFM Area 2E (Campbell et al. 2000). Vertical lines are 95% confidence intervals.

QUESTIONS:

Q: Were the attitudes of the community members measured before the stewardship program began?
A: No.

Q: How can you tell if attitudes have changed?
A: Before and after surveys were not done, there appears to be more community interest now.

Q: Are you doing intertidal surveys?
A: We have tried but it is very difficult to survey the intertidal areas.

Q: With respect to the sea otter issue, has there been any research feeding preferences?
A: At the Alaska Sea Otter commission presentation, Mark King said that sea otters will take what is visible and easy first.

Q: Is there sufficient political will to stop illegal harvest in this area?
A: Legislation and enforcement is required to reduce the poaching. We won't ever be able to totally stop poaching due to the amount of remote coastline to enforce. We need the resources to find the poachers, public education to add an element of peer pressure, and assistance to reduce local poaching. Public education will also help to get people to report illegal activities. People need to know that their help will make a difference.

THE KITASOO ABALONE STEWARDSHIP PROJECT: SMALL PROJECT, BIG HOPES [ABSTRACT]

by

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ABSTRACT

Harding, J. 2003. The Kitasoo abalone stewardship project: small project, big hopes [Abstract]. Can. Tech. Rep. Fish. Aquat. Sci. 2482: 20-22.

The Kitasoo Fisheries Program (KFP), operating out of the remote coastal First Nations community at Klemtu, has been working since 1995 to gain an understanding of northern abalone (*Haliotis kamtschatkana*) population demographics within the Kitasoo/Xaixais traditional territory. The traditional territory is large with one small village of 350 people. The objective of the KFP is to develop capacity within the Kitasoo/Xaixais Nation, to foster active community participation in the conservation and management of the fisheries resources in the region. The program covers many species, including salmon, herring, manila clams, urchin, prawn, sea cucumber, *Porphyra* and abalone. Over exploitation and depletion of northern abalone stocks has brought this species to the forefront of the program. A significant portion of the Kitasoo/Xaixais traditional territory has been surveyed for remnant abalone populations and information shared with Fisheries and Oceans Canada has helped to document the post-closure distribution of abalone. Inventory surveys were initiated in 1995 at sites throughout the area. A study site was established in south Nowish Inlet during 1999. Since then data on abalone growth from tagging, habitat requirements, predator and competitor relationships to abalone abundance, have been recorded.

In 2001, the KFP and the Habitat Stewardship Program initiated the Kitasoo Abalone Stewardship Project, with the purpose of expanding the scope and capacity of abalone rebuilding efforts while joining with local stewardship initiatives, such as education and monitoring campaigns. The main objective of this program is to rehabilitate local abalone populations to self-sustaining levels within the Kitasoo/Xaixais traditional territory. The level of community support and participation will determine the success of the program. Community workshops and follow-up meetings, since 2002, have raised awareness and encouraged local participation in project initiatives. Ongoing outreach efforts include project updates on the community radio

channel, distribution of material to visitors and tourists and youth education activities. The project has promoted participation by supporting those able to combine local food fishing activities with voluntary monitoring. The KFP used local knowledge and past survey information to establish two new stewardship areas to provide sites for evaluation of wild stock manipulation as a means to increase abalone densities and reproductive success. In addition, artificial cement habitats (condos) are being evaluated as an index tool to monitor juvenile recruitment and abundance. To date, juvenile abalone have been found in the condos, but whether the abalone density data from the condos are representative of wild resident juvenile densities or are useful as an index tool to monitor changes in juvenile abundance over time is still unclear.

The negative effect of illegal harvesting on recovery efforts is likely substantial. Increased local monitoring and decentralisation of enforcement power, from Fisheries and Oceans Canada to community based programs, would benefit the abalone resource, stewardship programs, enforcement agencies and communities involved. The KFP is a strong proponent of information exchange on this project and is eager to develop working partnerships with other abalone stewardship groups. The project is taking an ecosystem-based approach to abalone recovery where all work undertaken is within the constraints of the natural environment.

QUESTIONS:

Q: What was the shallow end depth of the sample sites and what type of kelp cover was evident with respect to the effect it might have on larval dispersal?
A: The depth was roughly 8 feet below datum, at some sites this was slightly different due to the bottom geography. There was only *Nereocystis* in the area and the cover varies widely. We did not look at larval dispersal in this study.

Q: Was there any *Macrocystis* in the area?
A: No.

Q: Can you take the condos apart underwater?
Y: Yes, we used turnbuckles on the chains to enable this.

Q: Are the juveniles you found in the condos naturally recruited or were they planted?
A: No (stock) manipulations have been done, so all recruitment was natural.

Q: Have you seen changes in how the adult abalone aggregate?
A: We didn't address aggregation in this study. We hope to do further research next year.

Q: How did you choose the sites for the condos? Did you have to use flat sites to place them?
A: We didn't select flat rock as there is not much opportunity for the abalone to disperse around the condo in that type of environment. We tried to select areas with crevices in bedrock because the condos cannot be anchored properly on boulders. We also tried to keep the substrate types consistent throughout the experimental plots to minimize environmental variation between sites.

Q: Have you considered putting the condos in areas with no rock, sand bottom for example, to prevent the adult abalone from leaving?
A: No. That would not be a good site to select for rebuilding efforts.

Q: Have you relocated any of the adults into the condos?
A: No, the condos were not intended for adults, they were meant to provide an indication of wild juvenile density and changes in that density over time.

Q: When looking at sites for broodstock aggregation, are you taking into account the current patterns with respect to larval dispersal?
A: Yes and no. We would like to consider larval distribution according to current patterns but it is difficult to take this variable into account. If we include control plots, we will definitely try to take current flow into account as much as possible to minimise larval transfer from treatments to control plots.

ABSOLUTELY ABALONE: HABITAT STEWARDSHIP PROGRAMME FOR THE PINTO ABALONE ON THE WEST COAST OF VANCOUVER ISLAND [ABSTRACT].

by

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ABSTRACT

Stewart, A. 2003. Absolutely abalone: Habitat stewardship programme for the pinto abalone on the west coast of Vancouver Island [Abstract]. Can. Tech. Rep. Fish. Aquat. Sci. 2482: 23-24.

Pinto or northern abalone (*Haliotis kamtschatkana*) were harvested traditionally at low tide, for millennia on the west coast of Canada. After intense diving harvests and an inability of management strategies to control harvests, the Pinto abalone was designated as a threatened species in 1999. The Bamfield Huu ay aht Community Abalone Project (BHCAP) was formed in response to a request for proposals, to work on abalone recovery on the west coast of Vancouver Island. The two key elements of the project strategy are to engage the community in abalone recovery and to operate a successful abalone hatchery for out-planting abalone. The objective of the project is the promotion of pinto abalone recovery through conservation, education and community engagement. Collaborations have been established been established with Fisheries and Oceans Canada, Canadian universities, the Nuu chah nulth Tribal Council and the Pacific Rim National Park Reserve.

Members of BHCAP are the Huu ay aht First Nations, Bamfield Community School Association and the Bamfield Marine Sciences Centre. The Huu ay aht First Nations have a goal of restoring abalone to the point where they can harvest for food and ceremonial use. The Community School Association is involved in building capacity. The Bamfield Marine Sciences Centre, a non-profit society with five western Canadian universities as members, has a mandate for research and education in marine sciences. They provide a base of operation for both the abalone education and research programs and the co-ordination of the dive program for abalone surveys, collections and out-planting.

Public education is a major component of the program and 3500 students per year, including students from school, college and universities, adult programs and the Community

School learn about abalone conservation biology. Raising the profile of the stewardship project at public events also inspires concern for abalone habitat and the kelp forest ecosystem for thousands of people. The Ocean Link website (www.oceanlink@island.net) provides a wealth of information on abalone and on this project and had over 8 million hits in 2001.

To reduce abalone poaching, the Huu ay aht First Nations crews patrol traditional territories and Coast Watch members keep a look out for poaching. Fishers, boaters, crews, lodge operators, and dive operators are also part of the Abalone Coast Watch.

Future plans include out-planting projects in conjunction with Fisheries and Oceans Canada, sourcing funding options and continuation of education, outreach and community engagement to strengthen community involvement. This last aspect is especially important to reduce illegal harvesting. This project is a fine example of First Nations and non-First Nations groups working together. With hard work and co-operation, the future of a healthy and sustainable abalone community and ecosystem is possible.

STATUS OF ENFORCEMENT

HAVE WE GOT PROBLEMS [ABSTRACT].

by

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ABSTRACT

Jubinville, B. 2003. Have we got problems [Abstract]. Can. Tech. Rep. Fish. Aquat. Sci. 2482: 26-27.

Do we have problems? Yes we do - on two fronts, 1) the continued illegal harvesting of northern abalone (*Haliotis kamtschatkana*) and 2) the reduction of reports on illegal activity. Essentially the same core group of fisheries officers has been enforcing the abalone fishery closure and has advocated protection of northern abalone in British Columbia (BC) since the closure started in 1990. We have received considerable support from other jurisdictions both within and outside the province, from stakeholders, the public, and federal Science and Fish Management branches. In the early 1990s, the conservation and protection of abalone started slowly, with the development of public and informant contacts, the creation of an awareness campaign using multi-lingual posters, media contacts, court cases, impact statements, convictions, imaginative sentencing efforts by lawyers and judges, and video clips. Protection has progressed which includes the ability to identify the species DNA footprints, the development of abalone stewardship groups and the fostering of contacts with the public. Public support in enforcement is critical. When the public observes, records and reports poaching activity to enforcement officers, all reports are examined and the information provided assists in developing a file and an investigation. Although some of the information received may prove to be of little value, some can be of significant value resulting in a conviction.

Six years ago, fisheries officers would receive numerous calls each year, which they would investigate. A file would be created and, if possible, poachers prosecuted with success. I do not know of a file that we have failed on when we have had the accused in possession of northern abalone. However, recently important information being provided has diminished. Is it because the amount and the quality of effort by the fishery officers in the field have increased resulting in an exceptional job of enforcing the closure in BC? Are the illegal harvesters now more reluctant to poach abalone because of the increased deterrence created? I would like to

think that these are the answers, but I am realistic enough to know there is a bigger picture in terms of the global problem of poaching abalone. Recently, South Africa reported that the annual seizure of illegal abalone had exceeded the legal harvest. I have to conclude that our northern abalone is under similar pressure. So where are the general public reports of illegal activity? I believe that we need another method of getting the message out to the public in order to increase the information being sent to us. The Haida Gwaii stewardship emphasises that "every tip counts" and the guardians will be documenting and sending reports. This should foster credibility for Fisheries and Oceans Canada and the guardians in the communities. Perhaps in addition to the telephone, word of mouth and other means of communicating, such as an internet tip line, would be helpful. Do we have a problem? Yes, we do and one aspect of the problem is the recent reduced information provided on illegal abalone harvesting activity. We need the assistance of the public and from communities throughout coastal BC in observing and reporting poaching incidents.

QUESTIONS:

Q: Does either the Coast Watch or the Abalone Watch contact you with reports about poaching?
A: Yes, but we would expect this situation because they are both quasi-enforcement agencies. The general public is the best source of information because they are not uniformed "officers" out watching for illegal activities.

Q: What sort of programs are present at the user end of the black market - in the markets and restaurants selling illegally harvested product?
A: We have market probes conducted by both uniformed and plain-clothes officers to attempt to quantify the sale of illegally harvested abalone.

Discussion: The illegal fishery is becoming more sophisticated; it is no longer the "little guys" that are out there. Illegal harvesters are also likely organised internationally. It is not so much that information from the public contacts has reduced, but that the public is simply not seeing the poaching. The best way to stop the problem would be to tackle it at the end user, most likely the buyers in the east.

AQUACULTURE

RECENT PROGRESS IN HATCHERY PRODUCTION OF PINTO ABALONE, *HALIOTIS KAMTSCHATKANA*, IN BRITISH COLUMBIA, CANADA.

by

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ABSTRACT

Pearce, C. M., P. Ågerup, A. Alabi, D. Renfrew, J. Rosser, G. Whyte, and F. Yuan. 2003. Recent progress in hatchery production of pinto abalone, *Haliotis kamtschatkana*, in British Columbia, Canada. Can. Tech. Rep. Fish. Aquat. Sci. 2482: 29-44.

In July 1999, Fisheries and Oceans Canada issued a Request for Proposals for 18-month pilot projects that would develop land-based hatchery rearing techniques for the pinto abalone, *Haliotis kamtschatkana*. A percentage of the cultured juveniles produced were to be utilised for wild stock rebuilding. Six projects were initially approved and five proceeded with the collection of wild broodstock for the purpose of developing hatchery techniques. Of these projects, three were successful at rearing substantial numbers of juveniles (i.e., Bamfield Huu-ay-aht Community Abalone Project, Island Scallops Ltd., and Malcolm Island Shellfish Co-operative). Their techniques for broodstock conditioning, spawning, larval rearing, larval settlement, and early juvenile grow out are summarised in this review paper. Adult broodstock were conditioned with wild kelp (*Laminaria saccharina*, *Macrocystis integrifolia*, *Nereocystis luetkeana*) and spawned using hydrogen peroxide, temperature shock, and/or UV-treated seawater. Larvae were reared in flow-through or static systems at 11-15°C at a density of 1-9 larvae ml^{-1} and settled on wavy or flat plastic sheets covered with natural biofilms of various ages. Early juveniles fed on benthic diatoms and were later converted to kelp and/or prepared diets. Grow out time to commercial size is predicted to be four to six years. To date, these three projects have produced approximately 170,000 juvenile abalone of various sizes.

INTRODUCTION

Haliotis kamtschatkana (northern or pinto abalone) has been used for food, social, and ceremonial purposes by coastal First Nations along the north-west coast of North America since pre-recorded time. The first non-aboriginal harvest of pinto abalone in British Columbia began in the early 1900s (Thompson 1914). Small-scale recreational and commercial harvesting by SCUBA diving appeared in the province in the 1950s. Commercial landings prior to the early 1970s were low, but rapidly increased to a peak of 481.4 t in 1997 due to increasing market demand and technological advancements allowing exploration into remote fishing areas.

Stock surveys conducted by Fisheries and Oceans Canada (DFO) at index sites in the south east Queen Charlotte Islands (Fig. 1) and north central coast of British Columbia conducted every 3-5 years during 1977-2002 provided general time series trends indicating that the abundance of pinto abalone declined more than 75% between the period of 1977-1984 (Breen et al. 1978, Adkins and Stefanson 1979, Breen and Adkins 1979, 1982, Boutillier et al. 1984, 1985). With evidence of substantial resource depletion, a quota management system was developed that reduced annual landings to 47 t in 1985-1990. Further stock surveys at these index sites revealed that wild populations remained low and/or continued to decrease in the period from 1984 to 1990 (Farlinger and Bates 1986, Carolsfeld et al. 1988, Thomas et al. 1990, Farlinger et al. 1991) and conservation concerns led DFO to close the fisheries in 1990 to all user groups including First Nations, commercial fishers, and recreational harvesters. Surveys conducted in the 1990s since the fishery closure (Winther et al. 1995, Thomas and Campbell 1996, Campbell et al. 1998, 2000) have revealed that stocks have continued to decline – presumably due to Allee effects and illegal poaching (Jubinville 2000) – and the fishery closure has remained in effect until present. Population decline has been so drastic that the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) has listed the pinto abalone as a "threatened" species which has led DFO to implement rebuilding programs and draft a Recovery Strategy and Action Plan to guide recovery operations.

In the summer of 1999, DFO issued a Request for Proposals for 18-month pilot projects that would develop land-based hatchery rearing techniques for pinto abalone in British Columbia. The idea behind this request was that successful proponents would be given access to a limited number of wild broodstock for spawning and development of hatchery-rearing techniques with the proviso that a certain percentage of the cultured juveniles produced would be utilized for wild stock rebuilding programs. Six projects were initially approved and five proceeded with the collection of wild broodstock. Of these projects, three were successful at rearing substantial numbers of juveniles (i.e., Bamfield Huu-ay-aht Community Abalone Project, Island Scallops Ltd., and Malcolm Island Shellfish Co-operative). This article summarizes the findings of these initial projects, which have now come to a conclusion, and provides a look at the future development of pinto abalone culture in British Columbia.

METHODS AND RESULTS

The Bamfield Huu-ay-aht Community Abalone Project (BHCAP), Island Scallops Ltd. (ISL), and the Malcolm Island Shellfish Co-operative (MISC) are all privately owned organizations located in small coastal communities on Vancouver Island, British Columbia, Canada (Fig. 1). BHCAP is an equal partnership between the Huu-ay-aht First Nations, the Bamfield Community School Association, and the Bamfield Marine Sciences Centre located in Bamfield. ISL is a privately-owned shellfish hatchery located in Qualicum Beach that was contracted by the Kitkatla First Nations to conduct abalone hatchery research. MISC is a registered co-operative consisting primarily of a number of Malcolm Island residents located in Sointula.

Methods used by the three hatcheries to produce juvenile abalone are summarised in Tables 1 and 2. Adult broodstock (81-144 mm shell length, SL) were collected by SCUBA divers in areas that had been previously surveyed. The number of abalone collected from any given site was based on 1% of the lower 90% confidence limit of the estimated population of abalone (90-110 mm SL). Adults were transported back to the laboratories where they were sexed, measured, and tagged (plastic number tags cemented to the shells). Small tissue samples of the epipodial tentacles were taken and preserved for subsequent DNA analysis (Withler 2000). Adult abalone were placed in broodstock rearing tanks, held at ambient temperature (8-14°C), and fed kelp (*Laminaria saccharina*, *Macrocystis integrifolia* or *Nereocystis luetkeana*) *ad libitum* for a period of two to three months. Photoperiod regimes for broodstock conditioning were as follows: BHCAP (12:12 light:dark with incandescent light); ISL (12:12 light:dark with red light); and MISC (8:16 light:dark with natural and fluorescent lighting). Broodstock were reared in different tank systems: BHCAP (green fibreglass silo tanks), ISL (one ton circular tanks as well as 200-L barrel tanks), and MISC (black plastic maze tanks imported from Port Lincoln, South Australia).

Broodstock were spawned at BHCAP with the addition of hydrogen peroxide (Morse et al. 1977) coupled with a 2°C temperature increase; ISL with hydrogen peroxide or ultra-violet treatment of seawater coupled with a 2-4°C temperature increase; and MISC with ultra-violet treatment of seawater, a <4°C temperature increase, and hydrogen peroxide. Eggs were held in a monolayer at the bottom of static tanks at 11-15°C (BHCAP: 12°C, ISL: 11-15°C, and MISC: 12-14°C) with egg density ranging from 5-35 eggs ml^{-1} (BHCAP: 12 eggs ml^{-1}, ISL: 5-35 eggs ml^{-1}, and MISC: 7-13 eggs ml^{-1}). Time from fertilization to hatching in all facilities was 32-42 hr at 10-12°C.

The lecithotrophic larvae were reared at 10-15°C (BHCAP: 12°C, ISL: 11-15°C, MISC: 10°C). Static larval tanks were used by both BHCAP and ISL with a water change every 6 and 24 hours, respectively, while MISC used flow-through tanks with a 1 L min^{-1} flow rate. Larval density ranged from 1.0-9.0 larvae ml^{-1} with BHCAP at 9.0 ml^{-1}, ISL at 1.0-5.0 ml^{-1}, and MISC at 1.4-3.4 ml^{-1}. Time from hatch out to settlement was 250 hr at 12°C at BHCAP, 264 hr at 11°C at ISL, and 256 hr at 11°C at MISC.

Competent larvae were held in flow-through settlement tanks (raceways or troughs) at all three facilities. BHCAP used a flow rate of 24 tank exchanges d^{-1} at 8-12°C with a larval density of 0.1 larva ml^{-1}, ISL used 1-4 tank exchanges d^{-1} at 12-15°C with a larval density of 0.3 larva ml^{-1}, and MISC had 41-82 tank exchanges d^{-1} at 8-12°C with a larval density of 0.005-0.006 larva ml^{-1}. Settlement plates were hung vertically in the settlement tanks: both BHCAP and ISL used translucent PVC wavy plates while MISC used translucent PVC flat sheets. Settlement induction in all three facilities was via a natural diatom assemblage (*Navicula, Cocconeis, Nitzschia*, and *Amphora* spp.) developed on the settlement panels. Algal growth on the plates was controlled to maximize diatom production and minimize filamentous algal growth. This was done by controlling intensity/duration of light and by lightly scrubbing plates to remove larger filamentous algae. BHCAP also used gamma-aminobutyric acid (GABA: 0.001 g ml^{-1} for 30 min) in addition to diatom films to induce larval settlement and metamorphosis.

Juvenile grow out was either in raceways or troughs. At BHCAP, juveniles were placed in mesh baskets that were suspended in the settlement tanks, at ISL the animals were held loose in the settlement tanks, and at MISC the animals were held loose in a wave tank. All groups held the juveniles in flow-through systems: 8-12°C with 24 tank exchanges d^{-1} (BHCAP), 7-17°C with 1-7 tank exchanges d^{-1} (ISL), and 8-12°C with 120 tank exchanges d^{-1} (MISC). Early juveniles fed on natural diatom assemblages. Later juveniles were supplemented with *Nereocystis luetkaena* (BHCAP); a mixture of *Laminaria saccharina, Macrocystis integrifolia*, and prepared feed developed by Adam and Amos (ISL); and prepared feed developed by MISC (MISC).

The BHCAP, ISL, and MISC projects came to a close in the summer/fall of 2002 (N.B. with an authorized extension, the projects ended up being longer than the proposed 18 months). At the end of the initial pilot projects, the organizations had produced the following numbers and sizes of juveniles: BHCAP (700 abalone of 25 mm SL and >100,000 abalone of 1-10 mm SL), ISL (20 abalone of 60-70 mm SL, 400 individuals of 30-50 mm SL, and 200 individuals of 10-20 mm SL), MISC (approximately 70,000 abalone of 5-20 mm SL). The three facilities estimate that it will take a total of 4-6 years from spawning to reach a market size of 65-110 mm SL.

DISCUSSION

The number of individuals produced (>170,000 juveniles) by the three projects was encouraging given the relatively short experimental time and that these were some of the first industrial-based hatcheries for pinto abalone. Based on a review of the project's progress and the potential contributions to be made to abalone recovery through research, community stewardship, and awareness, a second request for pinto abalone aquaculture proposals was issued by DFO in August 2002. Of six proposals submitted, two were approved in principle [BHCAP and MISC (N.B. ISL opted not to continue with abalone hatchery development at that point in time)]. These projects may collect a limited number of broodstock for the next five years to continue with the development of pinto abalone hatchery techniques. The projects are conditional on the proponents conducting wild stock reseeding experiments with a portion of the juveniles produced.

While great strides have been made in pinto abalone hatchery development in the last two years, much more research is required to fully maximize juvenile production. The biggest bottleneck to hatchery production is early juvenile survival – mortality rates are highest in the first six months post settlement (P. Ågerup, A. Alabi, G. Whyte, pers. obs.). Future research should concentrate on the potential factors influencing early juvenile survival including: 1) larval quality, 2) larval settlement and metamorphic cues, and 3) early post-settlement feeding. Larval quality may be affected by broodstock nutrition and/or larval uptake of dissolved organics or bacteria. Experiments should examine the potential effect of feeding adult broodstock various diets (both natural and prepared) on egg, larval, and early juvenile survival and quality (as measured by such factors as protein, lipid, and carbohydrate content). While larvae of other species of marine invertebrates (including red abalone, *Haliotis rufescens*) have been shown to uptake dissolved organic matter (Bass et al. 1969, Jaeckle and Manahan 1989, Manahan 1990, Welborn and Manahan 1990, Jaeckle 1994) or ingest bacteria (Rivkin et al. 1986, Pearse et al. 1991, Douillet 1993, Gosselin and Qian 1997) during their larval phase, this has yet to be demonstrated for pinto abalone. Even if they are capable of utilizing such material, would this then translate to superior larval or early juvenile performance?

Different species of abalone have been shown to settle and metamorphose in response to a variety of different cues including natural biofilms, coralline red algae (Morse et al. 1984, Morse and Morse 1984), conspecific mucus (Ino 1966, Seki and Kan-no 1981, Slattery 1992), GABA (Morse et al. 1979, Morse et al. 1980a, b), or elevated potassium ion concentrations (Baloun and Morse 1984). While pinto abalone are known to settle and metamorphose in response to both biofilms and GABA, no scientific research has determined what potential settlement cue(s) may be most effective in terms of settlement/metamorphic induction and post-metamorphic growth and survival.

Perhaps the most critical avenue to explore in terms of scientific research is the determination of the most suitable feeds for early post-settled individuals. Standard pinto abalone hatchery techniques at present allow young juveniles to graze natural biofilms which are complex communities consisting of a variety of bacteria, benthic diatoms, fungi, and protozoa. Presumably, juveniles feed primarily on benthic diatoms, but research is required to determine what components of the biofilm these young individuals are utilizing. Experiments need to be conducted to evaluate the suitability of various species of benthic diatoms and the possibility of using powdered prepared diets for early juvenile feeding (see Stott et al. 2003). Similar feeding studies will also be required for older juveniles which have switched to grazing on macroalgae. While survivorship at this stage is less of an issue, research is required to examine juvenile growth rates on various species of macroalgae and prepared diets.

The influence of disease or parasites is another area of research that may be important in the future development of pinto abalone culture. While the three hatcheries did not experience any widespread disease outbreaks during their operations, a protozoan (*Labyrinthuloides haliotidis*) pathogenic to juvenile pinto abalone has been isolated and identified in the past (Bower 1987). Other diseases/parasites have caused significant losses in abalone culture industries in other countries. The Rickettsiales-like prokaryote, *Candidatus xenohaliotis californiensis*, which causes withering syndrome, has been responsible for mass mortality of California populations of black abalone, *H. cracherodii*, and significant losses of cultured red abalone, *H. rufescens* (Friedman et al. 2000, Moore et al. 2001a, b). A sabellid polychaete, *Terebrasabella heterouncinata*, has caused severe problems in both the Californian and South African abalone aquaculture industries (Oakes and Fields 1996, Ruck and Cook 1998, Fitzhugh and Rouse 1999, Kuris and Culver 1999). As the pinto abalone culture industry in British

Columbia reaches commercial scale, high abalone densities and stressful environments associated with commercial culture may lead to problems with disease or parasites and scientific research will be required to address these problems.

The potential for culturing pinto abalone in British Columbia has generated much interest in recent years. This has been fuelled by the continued fishery closure, strong market prices for abalone, the existence of commercial abalone cultivation in other countries (e.g., Australia, Chile, China, Mexico, New Zealand, South Africa, Taiwan, and the United States), and the recent progress of the BHCAP and MISC hatcheries. Aquaculture of pinto abalone has piqued the interest of industry (commercial production of a highly valuable product), First Nations (cultural significance, food source, commercial opportunity, and wild stock rehabilitation), small coastal communities (job creation), and the federal government (enhancement of a "threatened" wild resource). Co-operatives such as BHCAP and MISC, that have active community and First Nation involvement, are a prime example of the grass-roots support for this type of aquaculture development. Aside from developing hatchery and grow out technology for pinto abalone, these groups are actively involved in community stewardship, teaching, and training.

The prospect of pinto abalone culture in British Columbia is being well received on environmental and social fronts. From an environmental perspective, the culture of pinto abalone is relatively benign since it takes place on land (N.B. the British Columbia provincial government has restricted sea-based culture) and makes use of primarily plant, not animal, protein for meeting feeding requirements. From a social perspective, pinto abalone culture has the support of many small coastal communities and First Nations who view the industry as a way of supporting economic growth and social structure within their communities. While not yet at a commercial-scale production level, it would appear that the development of pinto abalone culture within British Columbia has strong support on many fronts. Hopefully the next five to ten years will see the evolution of a profitable pinto abalone culture industry on the west coast of Canada.

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REFERENCES

Adkins, B.E. and A.P. Stefanson. 1979. North coast abalone survey in harvested areas, November 1978. Fish. Mar. Serv. Manuscr. Rep. 1500: 15 p.

Baloun, A.J. and D.E. Morse. 1984. Ionic control of settlement and metamorphosis in larval *Haliotis rufescens*. Biol. Bull. 167: 124-138.

Bass, N., G. Chapman, and J.H. Chapman. 1969. Uptake of leucine by larvae and adults of *Nereis*. Nature Lond. 211: 476-477.

Boutillier, J.A., W. Carolsfeld, P.A. Breen, and K. Bates. 1984. Abalone survey in the Estevan group and Aristazabal Island, May 1983. Can. Manuscr. Rep. Fish. Aquat. Sci. 1747: 60 p.

Boutillier, J.A., W. Carolsfeld, P.A. Breen, S. Farlinger, and K. Bates. 1985. Abalone resurvey in the southeast Queen Charlotte Islands, July 1984. Can. Manuscr. Rep. Fish. Aquat. Sci. 1818: 87 p.

Bower, S.M. 1987. *Labyrinthuloides haliotidis* n. sp. (Protozoa: Labyrinthomorpha), a pathogenic parasite of small juvenile abalone in a British Columbia mariculture facility. Can. J. Zool. 65: 1996-2007.

Breen, P.A. and B.E. Adkins. 1979. A survey of abalone populations on the east coast of the Queen Charlotte Islands, August 1978. Fish. Mar. Serv. Manuscr. Rep. 1490: 125 p.

Breen, P.A. and B.E. Adkins. 1982. Observations of abalone populations on the north coast of British Columbia, July 1980. Can. Manuscr. Rep. Fish. Aquat. Sci. 1633: 55 p.

Breen, P.A., A.P. Stefanson, and B.E. Adkins. 1978. North coast abalone surveys in harvested areas, spring 1978. Can. Manuscr. Rep. Fish. Aquat. Sci. 1480: 61 p.

Campbell, A., D. Brouwer, J. Rogers, and D. Miller. 2000. Abalone resurvey in the south east Queen Charlotte Islands, 1998. Can. Manuscr. Rep. Fish. Aquat. Sci. 2528: 30 p.

Campbell, A., I. Winther, B. Adkins, D. Brouwer, and D. Miller. 1998. Survey of the northern abalone (*Haliotis kamtschatkana*) in the central coast of British Columbia, May 1997. Can. Stock Assessment Secretariat Res. Doc. 98/89. Fisheries and Oceans Canada, 200 Kent Street, Ottawa, Ontario, Canada. 28 p.

Carolsfeld, W., S. Farlinger, B.C. Kingzett, N.A. Sloan, and G. Thomas. 1988. Abalone resurvey in the southeast Queen Charlotte Islands, June 1987. Can. Manuscr. Rep. Fish. Aquat. Sci. 1966: 90 p.

Douillet, P. 1993. Bacterivory in Pacific oyster *Crassostrea gigas* larvae. Mar. Ecol. Prog. Ser. 98: 123-134.

Farlinger, S. and K.T. Bates. 1986. Abalone survey in the Estevan group and Aristazabal Island, June 1985. Can. Manuscr. Rep. Fish. Aquat. Sci. 1896: 45 p.

Farlinger, S., G.A. Thomas, I. Winther, and W. Carolsfeld. 1991. Abalone resurvey in the Estevan group and Aristazabal Island, June 1989. Can. Manuscr. Rep. Fish. Aquat. Sci. 2104: 39 p.

Fitzhugh, K. and G.W. Rouse. 1999. A remarkable new genus and species of fan worm (Polychaeta: Sabellidae: Sabellinae) associated with marine gastropods. Invertebr. Biol. 118: 357-390.

Friedman, C.S., K.B. Andree, K.A. Beauchamp, J.D. Moore, T.T. Robbins, J.D. Shields, and R.P. Hedrick._ 2000. *Candidatus Xenohaliotis californiensis* a newly described pathogen of abalone, *Haliotis* spp., along the west coast of North America. Int. J. Syst. Evol. Microbiol. 50: 847-855.

Gosselin, L.A. and P.-Y. Qian. 1997. Can bacterivory alone sustain larval development in the polychaete *Hydroides elegans* and the barnacle *Balanus amphitrite*? Mar. Ecol. Prog. Ser. 161: 93-101.

Ino, T. 1966. Abalone science and its propagation in Japan. Fish. Res. Board Can. Trans. Serv. 1078: 209 p.

Jaeckle, W.B. 1994. Rates of energy consumption and acquisition by lecithotrophic larvae of *Bugula neritina* (Bryozoa: Cheilostomata). Mar. Biol. 119: 517-523.

Jaeckle, W.B. and D.T. Manahan. 1989. Feeding by a "non-feeding" larva: uptake of dissolved amino acids from seawater by lecithotrophic larvae of the gastropod *Haliotis rufescens*. Mar. Biol. 103: 87-94.

Jubinville, B. 2000. Enforcing the fishery closure for northern (pinto) abalone (*Haliotis kamschatkana*) in British Columbia. Can. Spec. Publ. Fish. Aquat. Sci. 130: 52.

Kuris, A.M. and C.S. Culver. 1999. An introduced sabellid polychaete pest infesting cultured abalones and its potential spread to other California gastropods. Invertebr. Biol. 118: 391-403.

Manahan, D.T. 1990. Adaptations by invertebrate larvae for nutrient acquisition from seawater. Am. Zool. 30: 147-160.

Moore, J.D., G.N. Cherr, and C.S. Friedman. 2001a. Detection of '*Candidatus Xenohaliotis californiensis*' (Rickettsiales-like prokaryote) inclusions in tissue squashes of abalone (*Haliotis* spp.) gastrointestinal epithelium using a nucleic acid fluorochrome. Dis. Aquat. Org. 46: 147-152.

Moore, J.D., T.T. Robbins, R.P. Hedrick, and C.S. Friedman. 2001b. Transmission of the Rickettsiales-like prokaryote "*Candidatus xenohaliotis californiensis*" and its role in withering syndrome of California abalone, *Haliotis* spp. J. Shellfish Res. 20: 867-874.

Morse, A.N.C. and D.E. Morse. 1984. Recruitment and metamorphosis of *Haliotis* larvae induced by molecules uniquely available at the surfaces of crustose red algae. J. Exp. Mar. Biol. Ecol. 75: 191-215.

Morse, A.N.C., C.A. Froyd, and D.E. Morse. 1984. Molecules from cyanobacteria and red algae that induce larval settlement and metamorphosis in the mollusc *Haliotis rufescens*. Mar. Biol. 81: 293-298.

Morse, D.E., H. Duncan, N. Hooker, A. Baloun, and G. Young. 1980a. GABA induces behavioral and developmental metamorphosis in planktonic molluscan larvae. Fed. Proc. 39: 3237-3241.

Morse, D.E., H. Duncan, N. Hooker, and A. Morse. 1977. Hydrogen peroxide induces spawning in molluscs, with activation of prostaglandin endoperoxide synthetase. Science 196: 298-300.

Morse, D.E., N. Hooker, and H. Duncan. 1980b. GABA induces metamorphosis in *Haliotis*, V: stereochemical specificity. Brain Res. Bull. 5: 381-387.

Morse, D.E., N. Hooker, H. Duncan, and L. Jensen. 1979. γ-aminobutryic acid, a neurotransmitter, induces planktonic abalone larvae to settle and begin metamorphosis. Science 204: 407-410.

Oakes, F.R. and R.C. Fields. 1996. Infestation of *Haliotis rufescens* shells by a sabellid polychaete. Aquaculture 140: 139-143.

Pearse, J.S., I. Bosch, V.B. Pearse, and L.V. Basch. 1991. Differences in feeding on algae and bacteria by temperate and Antarctic sea star larvae. Antarct. J. U.S. 26: 170-172.

Rivkin, R.B., I. Bosch, J.S. Pearse, and E.J. Lessard. 1986. Bacterivory: a novel feeding mode for asteroid larvae. Science 233: 1311-1314.

Ruck, K.R. and P.A. Cook. 1998. Sabellid infestations in the shells of South African molluscs: implications for abalone mariculture. J. Shellfish Res. 17: 693-699.

Seki, T. and K. Kan-no. 1981. Induced settlement of the Japanese abalone *Haliotis discus hanai* veliger by the mucus trails of the juvenile and adult abalone. Bull. Tohoku Fish. Res. Lab. 43: 29-34.

Slattery, M. 1992. Larval settlement and juvenile survival in the red abalone (*Haliotis rufescens*): an examination of inductive cues and substrate selection. Aquaculture 102: 143-153.

Stott, A., T. Takeuchi, Y. Koike, and O. Imada. 2003. Settling and raising postlarval abalone *Haliotis diversicolor supertexta* (Lischke) on microparticulate diets embedded in a layer of alginate. Aquacult. Res. 34: 561-567.

Thomas, G. and A. Campbell. 1996. Abalone resurvey in Aristazabal Island, the Estevan group and Banks Island, June 1993. Can. Tech. Rep. Fish. Aquat. Sci. 2089: 97-109.

Thomas, G., S. Farlinger, and W. Carolsfeld. 1990. Abalone resurvey in the southeast Queen Charlotte Islands in 1990. Can. Manuscr. Rep. Fish. Aquat. Sci. 2099: 66-82.

Thompson, W.F. 1914. Report on the abalones of British Columbia (*Haliotis gigantae*, Chemnitz) [*Haliotis kamtschatkana* Jonas]. Rep. B.C. Commissioner Fish., Victoria, B.C. (1913): 126-130.

Welborn, J.R. and D.T. Manahan. 1990. Direct measurements of sugar uptake from seawater into molluscan larvae. J. Exp. Mar. Biol. Ecol. 65: 233-239.

Winther, I., A. Campbell, G.A. Thomas, B.E. Adkins, and B.G. Clapp. 1995. Abalone resurvey in the southeast Queen Charlotte Islands, 1994. Can. Manuscr. Rep. Fish. Aquat. Sci. 2273: 46 p.

Withler, R.E. (2000) Genetic tools for identification and conservation of exploited abalone (*Haliotis* spp.) species. *In* A. Campbell [ed.]. Workshop on rebuilding abalone stocks in British Columbia. Can. Spec. Publ. Fish. Aquat. Sci. 130: 101-110.

Table 1. Summary results of broodstock conditioning, spawning, and larval hatch out for Bamfield Huu-ay-aht Community Abalone Project (BHCAP), Island Scallops Ltd. (ISL), and Malcolm Island Shellfish Co-operative (MISC).

	BHCAP	**ISL**	**MISC**
Broodstock			
Number of broodstock	53	165	49
Range of shell length (mm)	90-110	86-125	81-144
Number of males	22	17	9
Number of females	31	148	40
Number of mortalities	5	154	12
Mortality cause	technical[1]	technical[2], biological[3]	technical[4], biological[5]
Broodstock conditioning			
Type of feed	*Macrocystis integrifolia, Nereocystis luetkeana*	*Laminaria saccharina, Macrocystis integrifolia*	*Macrocystis integrifolia*
Tank shape	cylindrical with sloping conical bottom	cylindrical with sloping conical bottom	rectangular[6]
Tank colour	green	grey or green	black
Tank material	fibreglass	fibreglass (grey), polyethylene plastic (green)	plastic
Tank size (cm)	D x H: 74 x 58	D x H: 64 x 71	L x W x H: 260 x 160 x 20
Tank volume (L)	70	200	830
Broodstock habitat	black, half-cylindrical habitats (PVC)	black, half-cylindrical habitats (PVC)	none
Water temperature (°C)	9-14	13	8-10
Water flow rate (L min^{-1})	1	4	45
Lighting	12:12 light:dark (incandescent light)	12:12 light:dark (red light)	8:16 light:dark (natural and fluorescent light)

Table 1 (cont'd)

	BHCAP	**ISL**	**MISC**
Spawning			
Method	H_2O_2 with gradual increase to 2°C above ambient	H_2O_2 or UV treatment of seawater with gradual increase to 2-4°C above ambient	UV treatment of seawater with gradual increase to <4°C above ambient and H_2O_2
Sperm to egg ratio	5:1	5:1 to 10:1	5:1 to 10:1
Male to female ratio	1:1[7]	1:2[8]	1:6 to 1:2[9]
Water temperature (°C)	12	10-14	10-14
Fertilization-hatching time (hr)	42 at 12°C	40 at 10°C	32-40
Larval hatch out			
Tank shape	rectangular	rectangular	rectangular
Tank colour	white	blue	blue
Tank material	polyethylene	plastic	plastic (HDPE)
Tank size (cm)	L x W x H: 100 x 28 x 30	L x W x H: 50 x 35 x 41	L x W x H: 70 x 43 x 25
Tank volume (L)	84	72	75
Water temperature (°C)	12	11-15	12-14
Water flow rate	static[10]	static or gentle flow (~10-20 ml min^{-1})	static
Lighting	natural daylight	natural daylight and fluorescent light	8:16 light:dark (natural and fluorescent light)
Egg density	~1,000,000 eggs $tank^{-1}$ or ~12 eggs ml^{-1} [11]	360,000-2,500,000 eggs $tank^{-1}$ or 5-35 eggs ml^{-1} [11]	500,000-1,000,000 eggs $tank^{-1}$ or 7-13 eggs ml^{-1} [11]
Hatching-settlement time (hr)	250 at 12°C	264 at 11°C	256 at 11°C

[1] crawling out of tanks, stuck behind standpipes

[2] crawling out of tanks, temperature fluctuation due to mechanical failure

[3] *Polydora* sp., *Microsporidia*, Withering Foot Syndrome

[4] crawling out of tanks

[5] over spawning, cracked shells

[6] maze tank (technology imported from Australia)

[7] numbers depend on size of facility and adult ripeness

[8] typically about 5 males to 10 females

[9] typically about 1-2 males and 4-6 females

[10] no water flow until trochophores swim to surface then enough to move them into larval rearing chambers

[11] mono-layer on bottom of tank

Table 2. Summary results of larval rearing, larval settlement, and juvenile grow out for Bamfield Huu-ay-aht Community Abalone Project (BHCAP), Island Scallops Ltd. (ISL), and Malcolm Island Shellfish Co-operative (MISC). SL = shell length in mm.

	BHCAP	**ISL**	**MISC**
Larval rearing			
Tank shape	cylindrical[1]	cylindrical	rectangular
Tank colour	white	blue	white
Tank material	plastic (PVC)	fibreglass	plastic (HDPE)
Tank size (cm)	D x H: 25 x 41	D x H: 92 x 77, 128 x 92, 183 x 64 (3 different sizes used)	L x W x H: 70 x 60 x 35
Tank volume (L)	20	500, 1200, 1700	150
Water temperature (°C)	12	11-15 (14-15 best)	10
Water flow rate	static	static	1 L min^{-1}
Water exchange rate (tank volumes d^{-1})	4	0.5-1.0	10
Lighting	natural daylight	natural daylight and fluorescent light	8:16 light:dark (natural and fluorescent light)
Larval density (larvae ml^{-1})	9	1-5	1.4-3.4
Larval settlement			
Tank shape	rectangular	rectangular	rectangular
Tank colour	white or green	green	black
Tank material	fibreglass	plastic	plastic (HDPE)
Tank size (cm)	L x W x H: 300 x 90 x 60, 250 x 120 x 60, 300 x 120 x 60	L x W x H: 640 x 92 x 92	L x W x H: 230 x 130 x 35
Tank volume (L)	1000, 1350, 1700	3000	1050
Settlement sheet shape	square wavy plates	square wavy plates	square flat plates
Settlement sheet colour	translucent	translucent	translucent
Settlement sheet material	plastic	plastic	plastic
Settlement sheet size (cm)	L x W: 30 x 30	L x W: 61 x 30.5	L x W: 60 x 30

Table 2 (cont'd)

	BHCAP	**ISL**	**MISC**
Larval settlement			
Settlement sheet arrangement	10 plastic plates per basket stacked vertically	29 plates fixed vertically inside plastic coated metal racks[2]	120 plastic sheets per tank stacked vertically
Type of film	natural diatom assemblage[3]	natural diatom assemblage[3]	natural diatom assemblage[3]
Film age prior to settlement (d)	7-28	5-60	60 d
Water temperature (°C)	8-12	12.0-14.5 (favourable)	ambient (8-12) prefer heated (12-15)
Water flow rate (tank volumes d^{-1})	24[4]	1-2 after settlement to 4 when metamorphosis finished	41-82[5]
Lighting	fluorescent (duration/intensity dependent on grazing pressure)	fluorescent (duration dependent on grazing pressure)	natural daylight with shade cloth
Larval density (larvae ml^{-1})	0.1	0.3	0.005-0.006
Comments	manipulation of diatom growth through plate flipping and light covers	diatom growth and blue-green algae development manipulated by shading	manipulation of diatom growth through plate flipping and light covers
Juvenile grow out			
Tank shape	rectangular	trough	trough[6]
Tank colour	white or green	green	green
Tank material	fibreglass	plastic (polyethylene)	fibreglass
Tank size	L x W x H: 300 x 90 x 60, 250 x 120 x 60, 300 x 120 x 60	L x W x H: 640 x 92 x 92	L x W x H: 800 x 200 x 20 (water depth: 4)
Tank volume (L)	1000, 1350, 1700	3000	640
Water temperature (°C)	8-12	7.2-16.5	ambient (8-12) prefer heated (12-15)
Water flow rate (tank volumes d^{-1})	24	0.8-7	120

Table 2 (cont'd)

	BHCAP	**ISL**	**MISC**
Juvenile grow out			
Lighting	natural daylight	natural daylight	natural daylight with shade cloth
Juvenile density	dependent on size and feed available	no more than 0.3 juveniles ml^{-1} to start then quickly reduced	maximum 10 kg m^{-2}
Juvenile feed	diatoms followed by *N. luetkeana*	diatoms followed by *L. saccharina*, *M. integrifolia*, prepared feed (Adam & Amos)	diatoms on sheets (year 1) prepared feed (year 2+)
Size (SL)/age taken off sheets	5 mm, 10 months	at least 5 mm, 8-9 months	at least 5 mm, 8-9 months
Size (SL)/age weaned off diatoms	never	never	8-10 mm, 8-12 months
Comments	juveniles held in plastic mesh baskets in raceways	juveniles held free in troughs, fed macroalgae and diatoms	originally using Adam & Amos diet, but now using own diet
General			
Number of spawns	5	6	15
Number of juvenile batches	5	3	2
Number & SL of juveniles	700 at 25 mm >100,000 at 1- 10 mm	20 at 60-70 mm, 400 at 30-50 mm, 200 at 10-20 mm	70,000 at 5-20 mm
Time to commercial size (yr)	4-5	4-5	4-6 (possibly 3 with heated water)

[1] polyethylene water bath holds 6 rearing chambers with flow rate in bath enough to maintain temperature in chambers

[2] 10-12 racks are usually used per raceway

[3] includes *Navicula* spp., *Cocconeis* spp., *Nitzschia* spp., *Amphora* spp.

[4] 0.3, 0.4, or 0.5 L s^{-1} (depending on tank volume)

[5] 0.5-1.0 L s^{-1}

[6] wave tank (technology imported from Australia)

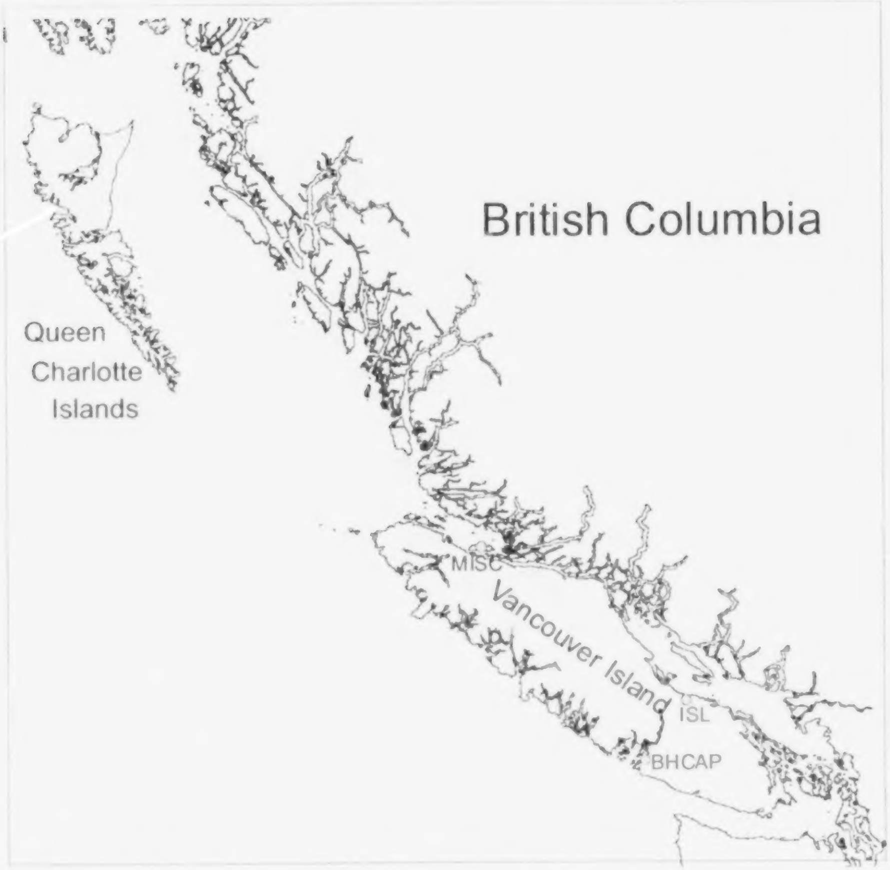
British Columbia
Queen Charlotte Islands
MISC
Vancouver Island
ISL
BHCAP

Figure 1. Map of west coast of British Columbia showing Vancouver Island, Queen Charlotte Islands, and locations of Bamfield Huu-ay-aht Community Abalone Project (BHCAP), Island Scallops Ltd. (ISL), and Malcolm Island Shellfish Co-operative (MISC).

QUESTIONS:

Q: Why are you looking into the effects of DOM (dissolved organic matter)?
A: The potential effects of algal exudates (DOM) on larval growth/survivorship and larval settlement success are unknown for this abalone species.

UPDATE ON EMERGING ABALONE DISEASES AND TECHNIQUES FOR HEALTH ASSESSMENT [ABSTRACT].

by

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ABSTRACT

Bower, S. M. 2003. Update on emerging abalone diseases and techniques for health assessment [Abstract]. Can. Tech. Rep. Fish. Aquat. Sci. 2482: 45.

This paper presents a review of new diseases and additional information on known pathogens of abalone that were encountered in the last few years as a result of increasing efforts towards the culture of abalone around the world and concurrent investigations into abalone health. A novel haplosporidian was associated with high mortalities (82.5 to 90%) of cultured juvenile paua (*Haliotis iris*) in New Zealand. Disease outbreaks among cultured abalone in Tasmania, Australia were associated with two species of *Vibrio* (*V. harveyi* and *V. splendidus* I) and a *Flavobacterium*-like bacterium with stress factors precipitating the diseases in most cases. The agent of withering syndrome responsible for mass mortalities of black abalone (*H. cracherodii*) in southern California was identified as the Rickettsiales-like prokaryote "*Candidatus* Xenohaliotis californiensis". And the exotic sabellid polychaete that seriously impacted abalone culture in California was named *Terebrasabella heterouncinata* and experimentally found to reproduce at low temperatures but with a significantly temperature dependant generation time (a developmental cycle of 298 days at 11.2 °C in comparison to 165 days at 15.6 °C). In order to assess the health of cultured abalone, histological examinations are essential. For histology, tissue samples (less than 1 cm thick) should be fixed in Davidson's solution or 10% formalin in sea water such that there is at least 10 parts fixative to 1 part tissue. Histopathology will not only indicate the presence of infectious agents but can be useful for monitoring the suitability of the diet and aquaculture environment. These assessments will benefit abalone aquaculture and provide assurance that only healthy animals are used in stock rehabilitation programs.

N.B. Full manuscript in Journal of Shellfish Research 22 (3) (in press).

EARLY REPRODUCTION IN HATCHERY-RAISED WHITE ABALONE, *HALIOTIS SORENSENI*, BARTSCH, 1940 [ABSTRACT}.

by

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ABSTRACT

McCormick, T. B. and J. L Brogan. 2003. Early reproduction in hatchery-raised white abalone, *Haliotis sorenseni*, Bartsch, 1940 [Abstract]. Can. Tech. Rep. Fish. Aquat. Sci. 2482: 46-47.

White abalone, *Haliotis sorenseni*, is the first marine invertebrate species to be placed on the endangered species list in the United States of America. A controlled breeding program is underway to provide stocks to re-establish wild populations of this species. There is no knowledge of the reproductive potential of early adults. This study examined the onset of gonad maturation and spawning capability of one-year-old abalone. Both hydrogen peroxide and ultra-violet irradiated seawater induced spawning in males and females as small as 25 to 35 mm in shell length. More males spawned in each treatment than females ($p<0.01$). The onset of gonad maturation is much smaller for white abalone than for other sympatric abalone in California. The implications for restocking strategies are discussed.

N.B. Full manuscript in Journal of Shellfish Research 22 (3) (in press).

QUESTIONS:

Q: Are you raising progeny from your spawners with the smaller shell length?
A: No.

Q: Are the eggs, from the small abalone spawners, the same size as the eggs of regular sized spawning adults?
A: The eggs are very small but we haven't specifically compared egg sizes.

Q: Have you decided what size of abalone to use for out-planting?
A: We think that 3-4 inches shell length would provide optimum protection from predators. There will be more work done in the future by government organizations to look into this.

Q: What is limiting the adult distribution of the white abalone?
A: The shells of white abalone are very thin and they can't compete with the other species, so they are forced offshore.

Q: If the densities of the other species were low, could you reseed the white abalone closer to shore in the shallower water?
A: No, white abalone are also highly poached in the few shallow environments where they are found. There would not be much point in seeding white abalone in shallow water.

Q: In South Africa, the F1 hatchery produced animals are of smaller size initially than the wild stock, but not necessarily in the second year. The question is, would the hatchery-reared animals react in a similar way in the natural environment after out-planting?
A: In the hatchery, abalone are reproductive all year and in the field from April to June only. Therefore, the early maturity of hatchery reared abalone may not have a long lasting effect when the animals are in the natural environment.

FIELD RESEARCH

NIGHT AND DAY SURVEYS OF A NORTHERN ABALONE (*HALIOTIS KAMTSCHATKANA*) POPULATION IN EAGLE BAY, BRITISH COLUMBIA

by

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ABSTRACT

Mortimor, J.P., C.R. Henderson, G.R.D. Elliott. 2003. Night and day surveys of a northern abalone (*Haliotis kamtschatkana*) population in Eagle Bay, British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 2482: 49-64.

This study, initiated by the Bamfield Huu ay aht Community Abalone Project (BHCAP), attempted to establish characteristics of behaviour and site selection, for possible out-planting of northern abalone (*Haliotis kamtschatkana*). Diurnal and nocturnal surveys were undertaken to determine population estimates of emergent juvenile and adult abalone at one small area in Barkley Sound. While using conventional methodology the survey conducted was intensive and small scale in nature, contrasting with previous studies that established abalone population estimates over broader areas. No clear community associations were identified, however behavioural and physical constraints were established. Recommendations for increasing out-planting effectiveness include out-planting juvenile abalone at night, between 4 and 6m below chart datum, on structurally complex substrates.

INTRODUCTION

A number of large-scale abalone population surveys have been conducted throughout selected areas in Barkley Sound, British Columbia B.C., Canada (Breen 1980, Emmett and Jamieson 1985, Lucas et al. 2001, Quayle 1971). These types of surveys are useful for determining overall size of the population and maintaining a time series of population data. Fisheries and Oceans Canada has developed a draft Recovery Strategy for abalone in B.C. (Toole et al. 2002). In developing appropriate strategies to rehabilitate declining populations it is important to gain an understanding of the spatial scale of stock units or metapopulations (Toole et al. 2002). More specifically, in determining suitable out-planting strategies, an understanding of the small-scale distribution of size classes, environmental and habitat characteristics and community preferences is advantageous for beneficial abalone rehabilitation.

Abalone are not randomly distributed. According to Breen (1980), they are "over-dispersed", exhibiting clumped aggregation. Due to this patchy distribution, Prince et al. (1998) suggested that a small spatial scale of monitoring and management is appropriate. Furthermore, within the Fisheries and Oceans Canada Recovery Strategy for Northern Abalone in British Columbia (Toole et al. 2002) there is recognition of the necessity for intensive local fine-scale surveys to be conducted, to determine ecological variability, within a genetically homogenous (Withler et al. 2001) northern abalone population. One of the goals of this survey was to complete a fine scale survey of the abalone population at a location in southwest Barkley Sound.

Most abalone surveys conducted in B.C. waters have concentrated on adult populations, with all surveys conducted during daylight hours (Kruse 1991). Our survey investigated the population structure of juvenile abalone. Juvenile abalone may exhibit greater emergence at night, spending the daytime hidden from various visual predators in cryptic habitats (Shepherd 1973, Watson 2000). Most mature abalone (≥70mm shell length or SL) are “emergent” or “exposed” (Campbell 1996). This survey was the first in B.C. waters to include nocturnal abalone assessments. Any differences in size classes between day and night measurements may be of importance to successful out-planting, especially with regard to juveniles.

The aim of this study is to identify small-scale distribution of size classes, environmental and habitat characteristics and community preferences, as well as to determine densities, size frequencies and population estimates of emergent juvenile and adult abalone, through the use of diurnal and nocturnal surveys. As a result, suitable out-planting strategies for juvenile abalone may be established.

METHODS

This intensive, small scale survey was conducted during the period of February 14th to March 19th 2002, at the east end of Eagle Bay (locally known as Scott’s Bay), near Bamfield, B.C. (latitude 48°50.08’ N longitude 125°08.8’ W). The Eagle Bay site had previously received attention during the Aguilar Point large-scale abalone surveys (Lucas et al. 2001, D. Johnson Pers. Comm., Bamfield Marine Sciences Centre, Bamfield). Anecdotal sources suggested that the study site historically supported abundant abalone. This area was identified as a possible candidate site for out-planting abalone due to the ease of access for protection against potential poaching under a “Coast watch” program, and the greater degree of physical protection compared to other sites for conducting diving work associated with out-planting.

The transect survey method described in Cripps and Campbell (1998) was adopted within the small study area. Transects were randomly placed perpendicular to the shore along the length of shoreline to be surveyed. To avoid bias, transect positions were determined in advance using random grid plots on a nautical chart. A transect consisted of a semi-permanent lead line laid perpendicular from a fixed weighted point at the rocky reef edge (or 12m diver’s gauge depth if the reef dropped to a greater depth) to a fixed point on the shore (or as shallow water as possible). Each transect was surveyed during daylight hours (diurnal surveys) and then subsequently after dusk (nocturnal surveys). A transect was the primary sampling unit. Each transect consisted of a number of secondary units, or quadrats. Starting at the deeper end of the transect line (the rocky reef edge), a 1m x 1m quadrat was placed alongside the line. The quadrat was flipped parallel to the transect line from deep to shallow. The initial quadrat and every other (odd numbered) quadrat were surveyed until water depth became too shallow or conditions (e.g. surge or waves) did not allow divers to continue.

One diver was tasked with measuring the size and recording the number of emergent abalone within the quadrat and the gauge depths (to be subsequently converted to depths below chart datum) along the transect. Abalone were divided into size classes of "small juveniles" (<50mm SL: Campbell et al. 1992, Cripps and Campbell 1998, Quayle 1971),"juveniles" (<70mm SL, including the small juveniles: Campbell et al. 1992, Campbell 1996), "mature" abalone (≥70mm SL: Campbell et al. 1992, Campbell 1996) , and "broodstock" (90-110mm SL: A. Campbell Pers. Comm., Pacific Biological Station, Nanaimo). A second diver recorded videographic documentation of the quadrats surveyed for later analyses of substrate types (Fisheries and Oceans Canada classification: crevice bedrock, smooth bedrock, boulder, cobble, gravel, pea gravel, sand, silt), algal cover (canopy, understory, turf, encrusting) and benthic invertebrates.

To obtain estimates of mean abalone density, population size and confidence intervals, the two data sets (diurnal surveys and nocturnal surveys) were analyzed according to Fisheries and Oceans Canada methodology (Campbell et al. 1999). The estimated area (m^2) of the study site was calculated by multiplying the mean transect length (as transects generally covered the full width of abalone habitat) by the length of shoreline sampled (provided by plotting GPS coordinates on a nautical chart) (Lucas et al. 2002).

Abalone data along with corresponding data on substrate, algal cover and benthic invertebrates were analyzed using PRIMER (Clarke and Gorley 2001, Clarke and Warwick 2001) techniques. The BIOENV procedure was used to establish any abalone associations with substrate, algae and benthic invertebrates.

RESULTS

Ten transects were sampled, 5 diurnal and 5 nocturnal (overlaid upon one another) over a shoreline length of 100m. The depths surveyed ranged from 11.4m below chart datum to 0.5m above chart datum (chart datum as defined by the Canadian Hydrographic Service). The mean transect length was 17.4m and the total survey area was calculated to be $1740m^2$.

A total of 46 abalone were counted from quadrats in the survey area, 17 during the diurnal and 29 during the nocturnal surveys. Sizes of abalone surveyed ranged from 8 to 119mm SL, the range being 8 to 116mm SL during the diurnal surveys and 12 to 119mm SL during the nocturnal surveys (Figure 1a, 1b). More individuals were counted at night than during the day, for all size classes (Figure 2). Only one transect, the least exposed, recorded no abalone for both diurnal and nocturnal surveys.

The majority of juveniles (including small juveniles) were found at 4-6m below datum (this is most evident from the nocturnal surveys due to a greater abundance of emergent juveniles), with a distribution of 2-6m in diurnal and 2-8m in nocturnal surveys. Juvenile abalone were not encountered in the shallowest zones (<2m). Mature abalone occurred from 2-6m in diurnal surveys, showing a preference for 2-4m, and a nocturnal distribution of 0-6m with a slight preference for 0-2m (Figure 3a, 3b).

The maximum density of emergent abalone on a diurnal transect was 0.5 per m^2, contrasting with the maximum density of emergent abalone on a nocturnal transect at 1.13 per m^2 (Figure 4).

The total population for the surveyed area estimated from the diurnal surveys was 644 abalone and from the nocturnal surveys was 1179 abalone (Table 1). For all size classes, there is a higher population estimate at night compared to the day estimate.

A t-test was performed to investigate whether the differences between day and night abalone counts were statistically different. For all size classes, the difference in the mean values of the two groups is not great enough to reject the possibility that the difference is due to random sampling variability. There is not a statistically significant difference between the input groups. The power of the performed tests is below the desired power; therefore negative findings should be interpreted cautiously.

The BIOENV analysis correlates the distribution and abundance of small juveniles, all juveniles, and mature abalone to the substrate (Table 2). There was no direct correlation with species assemblages at the community level BIOENV analysis, indicating that no biotic factors structure the abundance and distribution of juvenile or mature abalone.

DISCUSSION

The size frequency charts indicate a population that is composed of more mature abalone than juveniles. This "top heavy" population structure is typical of northern abalone (Breen 1980).

The surveys indicated that there was a difference in emergent abalone numbers between day and night, with higher abundances for all size classes at night. This was most evident for small juvenile and juvenile abalone. This was not supported by the statistical tests; however, this should be carefully evaluated. The lack of significant differences in statistical tests of abalone densities between night and day was probably due to limited sample sizes (number of transects) and the low abalone abundances in the small study area sampled.

Diurnal sheltering behaviour has been suggested by other studies (Day and Branch 2002), but not previously quantified for northern abalone in B.C. coastal waters. Interestingly, while less noticeable, there appeared to be higher numbers of emergent mature abalone at night (and a very small increase for the emergent broodstock abalone) than during the day. Kruse (1991). suggested that mature abalone did not exhibit day and night behavioural responses in B.C. waters. This may have implications for all abalone surveying in general, both surveys concentrating on juveniles and adults, in that density and population estimates may be lower if nocturnal surveys are not included. Considering the patchy distribution of abalone, any suggestion that populations are being under estimated requires a cautious approach by management. In terms of out-planting juvenile abalone, out-planting at night rather than during day may be more effective to allow juveniles to find suitable cryptic habitats.

Abalone were not spread out over the whole depth range surveyed. The juveniles appeared to prefer a deeper depth range than mature abalone. This may be due to increased physical disturbance (surge, currents, wave action and scour) in the shallow subtidal, while deeper there may be more suitable juvenile substrate and food (benthic diatoms) availability. Mature abalone may prefer a shallow distribution due to increased adult food availability (deposition of drift macroalgae) and substrate suitability. In terms of a strategy to out-plant juvenile abalone within this site the optimal depth would be 4–6m below chart datum.

The degree of exposure of the site may be of considerable importance when out-planting abalone. No abalone were recorded on the least exposed transect. However, this may be because this transect spanned the smallest width of habitat. Future studies should attempt to quantify environmental exposure and slope of the substrate for abalone suitability.

The BIOENV analysis shows interesting correlations between abalone and substrate preferences. When considering out-planting, there is a juvenile preference for what could be classed as "structurally complex" substrates, containing numerous cryptic sheltering places. Substrates that provide considerable refuge appear favored; for the juveniles these include cobble, pea gravel, and gravel. Small juveniles showed a positive correlation with pink encrusting algae, no significant correlation with articulated coralline algae and a negative correlation with red encrusting algae. This could be of importance as a substance produced by some encrusting algal species to trigger settlement from the planktonic phase (Morse and Morse 1984).

In this study BIOENV analysis does not suggest any clear relationships between abalone abundance and distribution with biotic factors, such as specific species or community assemblages. In other areas abalone are often associated with macroalgae (Watson 2000), however due to the high grazing pressure by red urchins macroalgal cover is relatively impoverished and this relationship may not be detectable. The small study area could be defined as an "urchin barren" (Rowley 1989) as is much of the rocky subtidal around Barkley Sound. The relationship between urchins and abalone may be of interest when considering the out-planting of juvenile abalone. Some studies suggest juvenile abalone may seek shelter (possibly from predation and/or physical factors) under the spines of urchins (Rogers-Bennett and Pearse 2001); this behaviour was not observed during these surveys. Also, intense fishing of abalone has led to invasion of abalone habitat by sea urchins, which prevents the full recovery of abalone (Karpov et al. 2001). In terms of rehabilitating abalone in an area, careful controlled urchin exclusion experiments may be a consideration.

Targeting small-scale surveys (akin to this study) within broader large-scale survey areas should be considered for future work. Additionally, within this small study area of Eagle Bay future studies could be made to determine growth rates of juvenile abalone and controlled experiments to assess the success of out-planting hatchery reared juveniles into the wild. This study has highlighted a number of requirements (depth, substrate, out-plant at night) that could be taken into consideration, and others to be investigated, in the rehabilitation of wild abalone stocks by out-planting juveniles.

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REFERENCES

Breen, P.A. 1980. Measuring fishing intensity and annual production in the abalone fishery of British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 947: 49 p.

Campbell, A. 1996. An evaluation of abalone surveys off southeast Queen Charlotte Islands. Can. Tech. Rep. Fish. Aquat. Sci. 2089: 111-121.

Campbell, A. and K. Cripps. 1998. Survey of abalone populations at Stryker Island, Tribal Group and Simonds Group, central coast of British Columbia, May, 1997. Can. Manscr. Rep. Fish. Aquat. Sci. 2451: 21 p.

Campbell, A., I. Manley, and W. Carolsfeld. 1992. Size at maturity and fecundity of the abalone, *Haliotis kamtschatkana*, in northern British Columbia. Can. Manscr. Rep. Fish. Aquat. Sci. 2169: 47-65.

Campbell, A., W. Hajas, and D. Bureau. 1999. Quota options for the red sea urchin fishery in British Columbia for fishing season 2000/2001. Can. Stock Assessment Secretariat Res. Doc. 99/201.

Clarke, K.R. and R.N. Gorley. 2001. PRIMER v5: User Manual/Tutorial. PRIMER-E: Plymouth.

Clarke, K.R., R.M. Warwick. 2001. change in marine communities: an approach to statistical analysis and interpretation, 2nd edition. PRIMER-E: Plymouth.

Cripps, K. and A. Campbell. 1998. Survey of abalone populations at Dallain Point and Higgins Pass, central coast of British Columbia, 1995-1996. Can. Manscr. Rep. Fish. Aquat. Sci. 2445: 31 p.

Day, E. and G.M. Branch. 2002. Influences of the sea urchin *Parechinus angulosus* (Leske) on the feeding behaviour and activity rhythms of juveniles of the south African abalone *Haliotis midae*. J. Exp. Mar. Biol. and Ecol. 276: 1-17.

Emmet, B. and G.S. Jamieson. 1985. An experimental transplant of northern abalone, *Haliotis kamtschatkana* in Barkley Sound, British Columbia. Fish. Bull. 87: 95-104.

Karpov, K.A., Tegner, M.J., Rogers-Bennett, L., Kalvass, P.E., and Taniguchi, I.K. 2001. Interactions among red abalones and sea urchins in fished and reserve sites of northern California: Implications of competition to management. J. Shellfish Res. 20: 743-753.

Kruse, G.O. 1991. Comparison of survey methods for sampling populations of northern abalone, *Haliotis kamtschatkana*. J. Shellfish Res. 10: 238.

Lucas, B.G., A. Campbell, D. Brouwer, S. Servant, and N. Webb. 2002. Survey of northern abalone, *Haliotis kamtschatakana*, populations in southeast Barkley Sound, British Columbia, July 2000. Revised Can. Manscr. Rep. Fish. Aquat. Sci. 2623: 11 p.

Morse, A.N.C. and D.E. Morse. 1984. Recruitment and metamorphosis of *Haliotis* larvae induced by molecules uniquely available at the surface of crustose red algae. J. Exp. Mar. Biol. Ecol. 75: 191-215.

Prince, J.D., C. Walters, R. Ruiz-Avila and P. Sluczanowski 1998. Territorial user's rights and the Australian abalone (*Haliotis* sp.) fishery. Can. Spec. Publ. Fish. Aquat. Sci. 125: 367-375.

Quayle, D.B. 1971. Growth, morphometry and breeding in the British Columbia abalone, (*Haliotis kamtschatkana* Jonas). Fish. Res. Board Can. Tech. Rep. 279: 84 p.

Rogers-Bennett, L. and J.S. Pearse. 2001. Indirect benefits of marine protected areas for juvenile abalone. Conservation Biology. 15: 642-647.

Rowley, R.J. 1989. Settlement and recruitment of sea urchins (*Strongylocentrotus* spp.) in a sea-urchin barren ground and a kelp bed: are populations regulated by settlement or poset-settlement processes? Marine Biology. 100: 485-494.

Shepherd, S.A. 1973. Studies on southern Australian abalone (genus *Haliotis*) I. Ecology of five sympatric species. Aust. J. Mar. Freshwat. Res. 24: 217-257.

Toole, J., B. Adkins, E. Bornhold, J. Boutillier, G. Caine, A. Campbell, A. Casteledine, I. Convey, C. Cote, P. Coulson, T. Down, K. Francis, H. Gill, R. Harbo, H. Holmes, B. Jubinville, D. Lawseth, B. Lucas, A. Morgan, G. Parker, and J. Rogers. 2002. National Recovery strategy for the Northern Abalone (*Haliotis kamtschatkana*) in British Columbia. Fisheries and Oceans Canada (www-comm.pac.dfo-mpo.gc.ca/pages/consultations/fisheriesmgmt/abalone/abaloneRecovStrategy_e.htm). 22 p.

Watson, J.C. 2000. The effects of sea otters (*Enhydra lutris*) on abalone (*Haliotis* spp.) populations. Can. Spec. Publ. Fish. Aquat. Sci. 130: 123-132.

Withler, R.E., A. Campbell, S. Li, K.M. Miller, and B.G. Lucas 2001. High levels of genetic variation in northern abalone, *Haliotis kamtschatkana*, of British Columbia. Can. Stock Assessment Secretariat Res. Doc. 2001/097.

Table 1. Estimated abalone population for Eagle Bay for an area of 1740 m^2; n=17 abalone during day and n=29 abalone during night. Total shore length consisted of 100m with a mean transect length of 17.4m. Values in brackets indicate 90% confidence intervals.

	Small juveniles	Juveniles	Mature	Broodstock	All abalone (all sizes)
Day	189 (158-219)	229 (162-295)	416 (276-554)	152 (81-222)	644 (395-893)
Night	407 (239-574)	488 (273-703)	691 (373-1008)	243 (141-346)	1179 (605-1752)

Table 2. Positive and negative correlations, determined by BIOENV analysis, used to assess distribution and abundance of various size classes of abalone compared to substrate. "+" represents a positive Spearman correlation coefficient ≥ 0.5, "-" represents a negative Spearman correlation coefficient ≤ -0.5.

	Pea Gravel	Cobble	Gravel	Crevice Bedrock	Smooth Bedrock	Boulders	Pink Encrust Algae	Red Encrust Algae	Articulated Coralline Algae
Small juveniles	+	+	+				+	-	
Juveniles		+						-	
Mature				+		+	+		

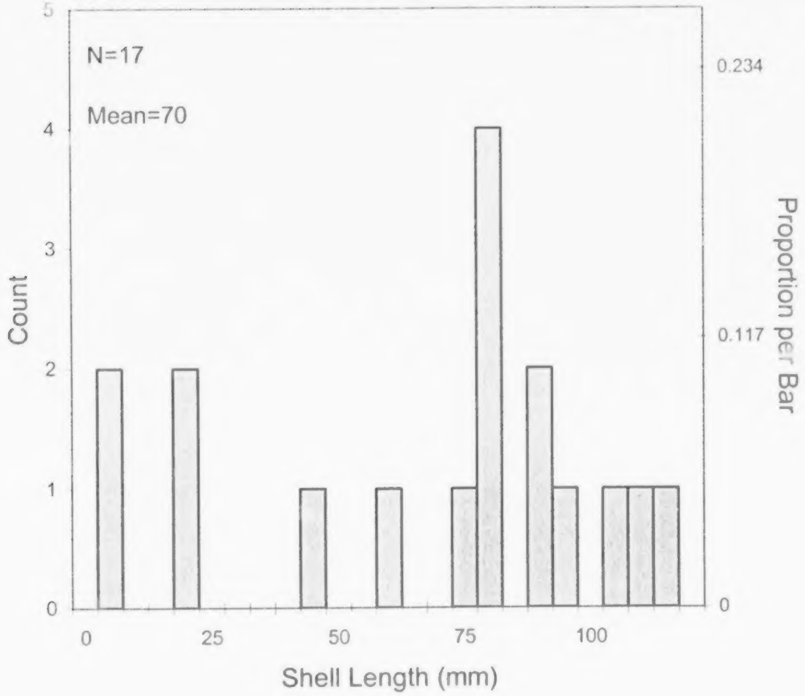

Figure 1a. Size frequencies of abalone from diurnal dive surveys of five transects at Eagle Bay.

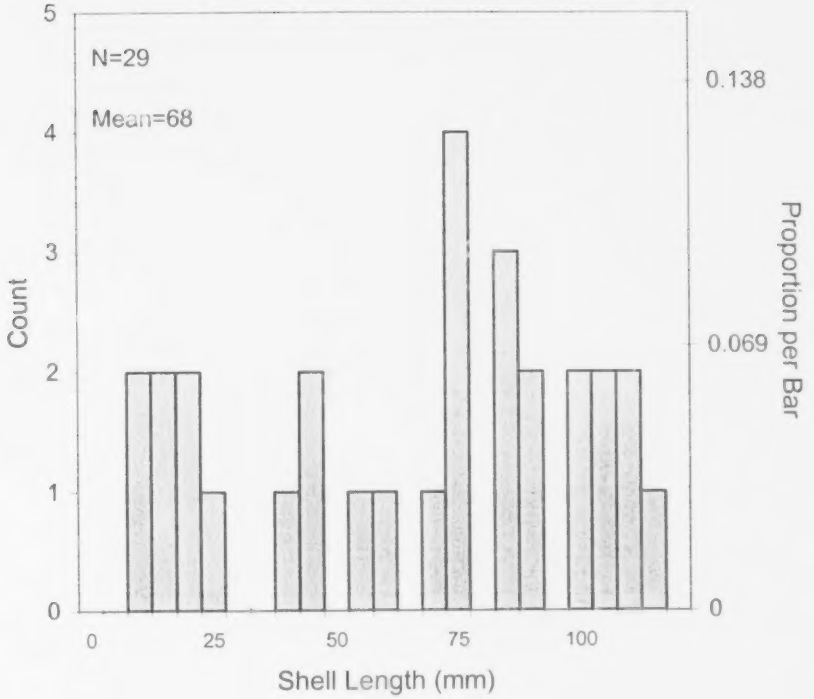

Figure 1b. Size frequencies of abalone from nocturnal dive surveys of five transects at Eagle Bay.

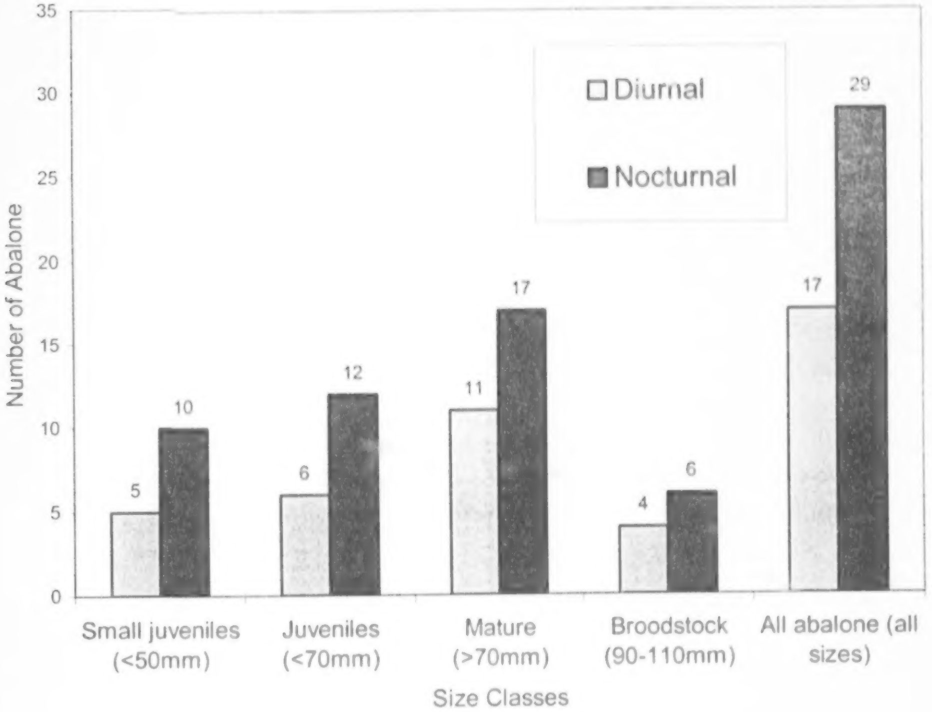

Figure 2. Total numbers of abalone located by diurnal and nocturnal dive surveys of five transects at Eagle Bay.

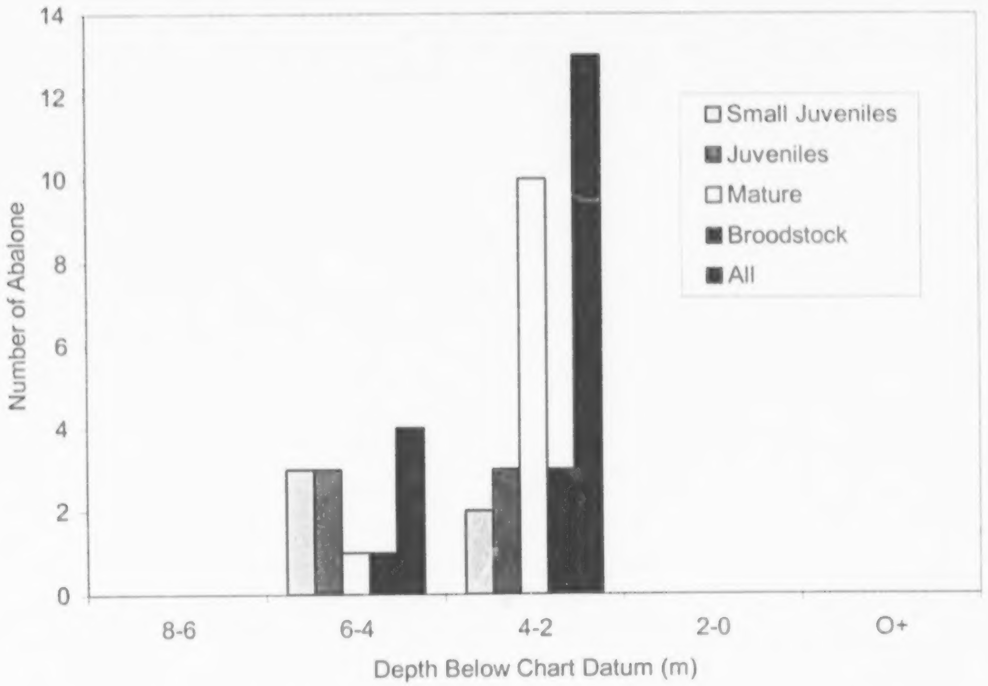

Figure 3a. Subtidal location of abalone of major size classes as measured in diurnal dive surveys of five transects at Eagle Bay.

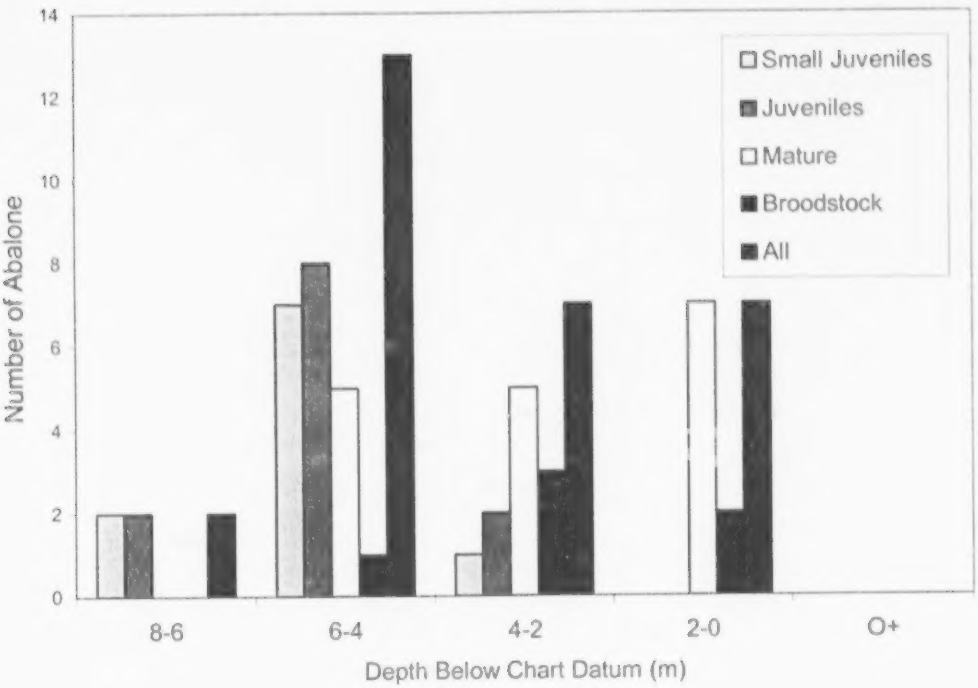

Figure 3b. Subtidal location of abalone of major size classes as measured in nocturnal dive surveys of five transects at Eagle Bay.

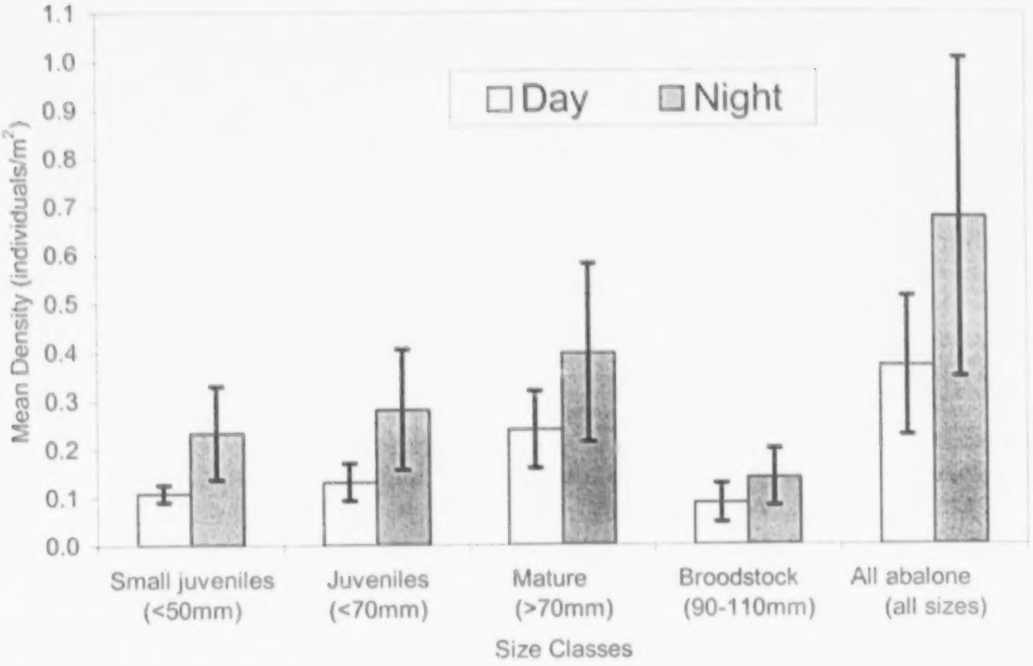

Figure 4. The mean densities of abalone during day and night surveys at Eagle Bay site for an area of 1740 m^2 ; n=17 abalone during day and n=29 during night. Total shore length consisted of 100 m with a mean transect length of 17.4 m. Error bars indicate 90% confidence intervals.

QUESTIONS

Q: Was there a difference in sampling time allocated to the day and night samples?
A: No, each quadrat was given the same amount of sampling time - day or night.

Q: What time were the surveys done?
A: The surveys were completed between 6 a.m. and midnight.

Q: Why did you choose to survey in February and March?
A: We would have liked to conduct the surveys at other times of the year, but were constrained by a lack of funding.

Q: During the nocturnal surveys, were the divers turning over more rocks? How many abalone were still left in the cryptic habitat - did all the abalone come out at night?
A: We did not disturb the substrate in any of the surveys. The methodology did not change between the day and the night survey; we assumed that the difference in numbers sighted was due to abalone hiding during the day.

Q: Did you look under the sea urchins?
A: Yes, for a consistent number of urchins for each survey, but not all of them.

Discussion: This is important work you are doing, it could impact the way that abalone are enumerated in the future and more research should be done in this area.

DISTRIBUTION AND ABUNDANCE OF *HALIOTIS KAMTSCHATKANA* IN RELATION TO HABITAT, COMPETITORS AND PREDATORS IN THE BROKEN GROUP ISLANDS, PACIFIC RIM NATIONAL PARK RESERVE OF CANADA [ABSTRACT].

by

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ABSTRACT

Tomascik, T. and H. Holmes. 2003. Distribution and abundance of *Haliotis kamtschatkana* in relation to habitat, competitors and predators in the Broken Group Islands, Pacific Rim National Park Reserve of Canada [Abstract]. Can. Tech. Rep. Fish. Aquat. Sci. 2482: 65-66.

Baseline information on the distribution and abundance of *Haliotis kamtschatkana* was obtained throughout the Broken Group Islands (BGI) in shallow- (2 – 5 m) and deep-water (6 – 9 m) habitats. The study demonstrates that abundance of northern (pinto) abalone varied spatially throughout the area and with depth. The shallow habitats in the study area supported significantly higher densities (0.18 abalone/m^2 ± 0.02 *SE*) of northern abalone when compared to deep habitats (0.10 abalone/m^2 ± 0.02 *SE*). Maximum and minimum sizes of northern abalone measured in BGI were 132 and 4 mm shell length (SL), respectively. There were significant differences in abalone SL among the 5 island groups and the 2 depth zones. Juvenile abalones were more abundant in the deep habitat than in the shallow habitat. A significant correlation was detected between abalone densities and the relative index of exposure. There was a positive correlation between abalone size and the abundance of benthic macroalgae and an inverse relationship between abalone size and the abundance of red sea urchins (*Strongylocentrotus franciscanus*). A positive correlation between abalone and red sea urchin densities was observed. Seven percent of juvenile abalone ($\leq$ 45 mm SL) was found under the red sea urchins' spine canopy. Distribution and abundance of selected invertebrate species associated with northern abalone including its known predators (i.e., sea stars, crabs, octopus) were assessed. The abundance of northern abalone was inversely correlated with predator abundance and density of benthic macroalgae. Detailed surveys of associated organisms and substrate types suggest that the distribution and abundance of northern abalone is a complex function of community interactions and substrate habitat characteristics.

N.B. Full manuscript in Journal of Shellfish Research 22 (3) (in press).

QUESTIONS

Q: Were all the data obtained from the same quadrats?
A: Not necessarily.

Q: In South Africa and Australia, we know that abalone have a tendency to aggregate and if the sampling technique doesn't take this into account, the data is skewed. Do Northern abalone aggregate and did you take this into account?
A: We have yet to develop a perfect sampling regime that takes everything into account. Our data indicated that clumping of northern abalone has never been as extreme as other abalone species. The distribution of northern abalone is patchy at best and there are no statistics on the number of samples needed to adequately represent such a distribution. To a certain extent, stratified sampling takes into account a clumped distribution. Another issue was that we needed randomness to keep the results simple and keep the model appropriate for use in other studies. Our objectives in this study were different from most sampling objectives, this study was to provide information on biodiversity as a base to indicate future changes. This technique would not be used to get absolute population values.

Q: To what extent does the Broken Group Islands abalone population now compare to the historical northern abalone population levels?
A: Historical evidence suggests that northern abalone were at one time found in such densities that they were stacked one top of one another and it was possible to harvest hundreds in half an hour, 2000 abalone in a single day, which equates to about 1500 pounds. This information came mostly from the Queen Charlotte Island/Hecate Strait area.

FECUNDITY AND SEASONAL REPRODUCTION OF NORTHERN ABALONE, *HALIOTIS KAMTSCHATKANA*, IN BARKLEY SOUND, CANADA [ABSTRACT].

by

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ABSTRACT

Campbell, A., J. Lessard, and G. S. Jamieson. 2003. Fecundity and seasonal reproduction of northern abalone, *Haliotis kamtschatkana*, in Barkley Sound, Canada [Abstract]. Can. Tech. Rep. Fish. Aquat. Sci. 2482: 67-68.

The fecundity, size at maturity and seasonal reproduction of northern or "pinto" abalone, *Haliotis kamtschatkana*, from exposed "surf" areas and more sheltered, productive abalone habitat were investigated in Barkley Sound. Examination of histological sections of gonads indicated that size at maturity occurred at a smaller size for the stunted 'surf' abalone than for abalone from more sheltered areas. The gonad index and stages showed that gonads were mainly ripe and that most abalone spawned during April to July. Although there were smaller abalone with ripe eggs from the "surf" area than those from the sheltered area, abalone females of comparable size from both areas had similar egg numbers. However, there were larger females with considerably higher fecundity from the sheltered areas than from the "surf" areas. Implications of transplanting "surf" abalone to productive habitats to increase growth and fecundity rates are discussed in the context of population rebuilding attempts for *H. kamtschatkana*, which is listed by the Committee on the Status of Endangered Wildlife in Canada as a "threatened" species in Canada.

N.B. Full manuscript in Journal of Shellfish Research 22 (3) (in press).

QUESTIONS

Q: Do you agree that the distance between the adults is more important than their density over the entire sample area?
A: Yes. We tried to aggregate the adults but were having difficulty finding them after we have moved them. There could be several reasons, the disturbance may have activated them and they

moved away, the high density could have attracted poachers, or perhaps we moved them too early in the season and they moved away before spawning. The study is continuing.

ESTIMATING JUVENILE NORTHERN ABALONE, *HALIOTIS KAMTSCHATKANA*, ABUNDANCE USING ARTIFICIAL HABITATS [ABSTRACT].

by

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ABSTRACT

DeFreitas, B. 2003. Estimating juvenile northern abalone, *Haliotis kamtschatkana*, abundance using artificial habitats [Abstract]. Can. Tech. Rep. Fish. Aquat. Sci. 2482: 69-70.

This study assessed the utility of artificial concrete block habitats that provide standardized sample areas for measuring the abundance of northern abalone (*Haliotis kamtschatkana* Jonas) in comparison to 10 randomly selected 1m^2 quadrat samples where all movable rocks were examined for cryptic abalone. A total of 278 abalone were measured within artificial structures and juvenile abalone ($\leq$50 mm shell length, SL) were the most abundant size class. Juvenile abalone used artificial structures at greater mean densities (abalone/m^2) than nearby natural habitat (1.27 ± 0.25 SE versus 0.07 ± 0.09 SE) and emergent abalone (>50 mm SL) used artificial habitats at similar densities as they did in nearby natural habitats (0.38 ± 0.09 SE versus 0.44 ± 0.10 SE). Juvenile abalone abundance was significantly different between sites but not within sites, suggesting artificial structures showed promise in their ability to detect area specific differences in recruitment and to easily measure juvenile abalone abundance.

N.B. Full manuscript in Journal of Shellfish Research 22 (3) (in press).

QUESTIONS

Q: Do the blocks in the condos have a constant surface area?
A: Yes, there are 24 similar shaped concrete blocks within each condo. Each artificial habitat provides approximately 3.5m^2 of available surface area.

Q: Would the cage limit food availability for the animals, or decrease the flow of drift algae through the condo?

A: It could be possible, but we find lots of kelp and algae growth on the mesh and on the concrete bricks.

Q: When we netted a beach to protect juvenile geoducks, we found that predators were getting under the net when they were small and became trapped under the net and, therefore, were able to eat what we were trying to protect. Did you notice this to be a problem with the cages?
A: The size of the stainless steel mesh allows free access to large abalone and all but the largest of predators (mainly sea stars). When artificial habitats were sampled, we did not find any large predators trapped within.

Q: Is the abalone density data cumulative? When you counted the abalone did you remove them or put them back?
A: During the sampling, most abalone found on the bricks would run away or fall off. If an abalone stayed on the brick they were left, if they ran away we didn't chase them down to put them back. The same is true of all the other creatures found on the bricks such as chitons, urchins, snails, limpets etc.

Q: Did you remove predators if you found them in the cage?
A: The predator survey was conducted in a similar way to the abalone density survey. If the predator ran away when we disturbed the cage, we didn't put it back; if it stayed, we didn't remove it, but if we had to move it to count the abalone, we did.

Discussion: One suggestion discussed was to change the brick configuration when each cage was sampled instead of trying to measure the amount of available cryptic habitat. In this manner, the habitat would be sufficiently random so as not to affect the methodology.

TRENDS IN PINTO ABALONE (*HALIOTIS KAMTSCHATKANA*) ABUNDANCE IN THE SAN JUAN ISLANDS AND MANAGEMENT OF ABALONE IN WASHINGTON STATE [ABSTRACT].

by

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ABSTRACT

Rothaus, D. P. and C. S. Friedman. 2003. Trends in pinto abalone (*Haliotis kamtschatkana*) abundance in the San Juan Islands and management of abalone in Washington State [Abstract]. Can. Tech. Rep. Fish. Aquat. Sci. 2482: 71-73.

Northern abalone are contagiously distributed in shallow, rocky, exposed, and kelp covered habitats from Sitka Alaska to Monterey California. In Washington State, abalone are found in the San Juan Islands, Strait of Juan de Fuca, and northern coastal waters. They are a slow growing species, reproductively mature at 25-50 mm shell length (SL) depending on location. In 1984, the sport harvest was estimated at 38,200 abalone annually and by 1991 this had increased to 40,934. Before 1992, regulations allowed a sport fishery for abalone of ≥ 90mm SL with a harvest limit of 5 abalone/day, and an abalone iron (for removal of abalone from rocks) was required. From 1992 to1994, the allowable harvest was 3 abalone per day, minimum size 102 mm SL, and an abalone iron and callipers were required. A total closure was instituted in August of 1994.

Stocks have declined in both British Columbia and Washington State, leading to the listing of northern abalone as a "Threatened Species" in Canada and as a "Species of Concern" in the USA. Common concerns and potential trans-boundary issues suggest co-operative restoration efforts between BC and Washington State may be valuable.

Surveys conducted throughout the San Juan Islands, 1979-1982, with timed 15-minute dives, have provided baseline information on abalone abundance and size for this area. 23 of these sites were again surveyed between 1990 and 1991. Abalone density at one site increased, at four sites stayed the same, at nine sites decreased, and at nine sites no abalone were found. The overall density decrease was approximately 50%. Locating the original 23 sites was

problematic and may have been a factor in the dramatic decrease observed. Even with the potential problems with this comparison, the magnitude of the apparent decline, combined with the anecdotal information from sport divers and University of Washington researchers, raised serious concerns about the health of abalone stocks in Washington. Further surveys were required to adequately evaluate the apparent trend in abalone abundance. As with other areas of the world, illegal harvesting is considered to have a major impact on the abalone stocks in Washington State.

In 1992, ten permanent abalone index dive stations were established around the San Juan Islands. The sites ranged in size from $50m^2$ to $380m^2$, averaging $220m^2$ with depths between 0 to –30 ft MLLW. Abundance and size of emergent abalone were determined over the whole site (census) with dives of 180-340 minutes bottom time. A declining trend in total abundance for all sites was observed 1992 to 1994 (n=351 to n=288), with no statistical difference. Following the fishery closure in August of 1994, the1996 survey results were n=297. Additionally, no significant difference in the mean shell length over time was observed. The average density of half the sites surveyed in 1996 was less than 0.15 abalone/m^2. Research indicates that sedentary invertebrates, such as abalone, must be within 1.0-2.0 m of one another (0.33-0.15 abalone/m^2) for successful fertilisation. Therefore, low population levels can lead to inability for gametes to cross fertilise resulting in recruitment failure. In Washington State, data shows that half of the index stations have abalone densities below the level for successful recruitment.

Recovery efforts include a captive broodstock project initiated in 2002 for the development of hatchery techniques using 80 abalone collected from Lopez Island. 16% mortality in the broodstock has occurred over the subsequent five months of captivity.

Anecdotal information and quantitative survey data suggests a decline in abalone populations in Washington State. Data from index stations shows a gradual decrease in abundance at six of ten sites but no overall significant change in abundance from 1992-1996. Some of the current index stations report abalone densities below the minimum density levels that are needed for successful recruitment.

Additional stock assessment studies will include the re-evaluation of the ten index sites in February 2003, more frequent (yearly) assessment of abalone abundance at the ten index sites, development of a better survey method so that population estimates can be obtained, creation of additional index sites in the Strait of Juan de Fuca, and initiation of juvenile abundance surveys. Genetics studies, in collaboration with Canadian scientists, will include analysis of relatedness between sites and between individuals within a site. The captive broodstock project will continue to culture abalone using techniques to maximise genetic diversity and to compare behaviour of hatchery reared animals in normal vs. "natural" tanks.

Should surveys show continued instability in abalone populations, management plans will be developed for abalone stock restoration, potentially including out-planting of hatchery raised juveniles and aggregation of adults. Public information meetings and scientific workshops will be held in co-operation with the Puget Sound Restoration Fund to raise public awareness.

QUESTIONS

Q: Do you always visit your sample sites in the winter (February to March)?
A: Yes, always. We can survey this time of year because our sites are quite sheltered compared to BC areas, as are the boat routes to get to the sites. The collection of information is easier this time of year because there is less kelp cover in winter and the divers can observe more of the bottom and spend less time moving algae.

Q: How long did it take for you to survey the entire site?
A: It was very time consuming. Depending on the site it took between 180 and 340 minutes of bottom-time for the divers to set-up and survey the entire site. We can only complete the survey for one station per day.

Q: Can you compare the densities with other sites or areas?
A: Because of the way the index stations were chosen, it is not possible to statistically compare densities between sites.

Q: Would it be possible to undertake transect or quadrat sampling now that you have an estimate of the densities of abalone at the entire sample site?
A: That is a good idea, however, the index sites were originally set up to get a snapshot of the abalone population in that particular area with the data not for use to extrapolate for the entire population. Data were originally for comparison between years within the same site only, not site to site.

Q: Do you have enough sites to amalgamate the data attained on sizes of the abalone?
A: Yes, we have done this in the past and we plan to continue to do it in the future.

Discussion: Random and/or adaptive sampling of the abalone in the area is theoretically a good idea but is logistically difficult. In 1996, Strait of Juan de Fuca tribes did some systematic adaptive sampling of red urchins. They evenly spaced transects along the shoreline starting at a random point with transects perpendicular to shore. A threshold density was determined and transects were added between the initial transects when the threshold density criteria was reached. This adaptive sampling technique might be applicable to abalone surveys but the statistical analysis is difficult.

IMPLICATIONS OF HIGH LEVELS OF GENETIC DIVERSITY AND WEAK POPULATION STRUCTURE FOR THE REBUILDING OF NORTHERN ABALONE POPULATIONS IN BRITISH COLUMBIA, CANADA [ABSTRACT].

by

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ABSTRACT

Withler, R. E., A. Campbell, D. Brouwer, S. Li, K. J. Supernault, and K. M. Miller. 2003. Implications of high levels of genetic diversity and weak population structure for the rebuilding of northern abalone populations in British Columbia, Canada [Abstract]. Can. Tech. Rep. Fish. Aquat. Sci. 2482: 74-75.

In the past 25 years, the abundance of northern abalone (*Haliotis kamtschatkana*) has declined by 80% in British Columbia (BC), leading to concern over a possible loss of genetic diversity and fragmentation of breeding aggregates in the species. Abalone from 31 sites in BC and one site in southeastern Alaska were surveyed for variation at eight polymorphic microsatellite loci. The high level of H_E characterising all samples resulted in a large estimated effective population size for northern abalone (>350,000), consistent with a high estimates for the historical average number of migrants entering abalone aggregations each generation (~20-125). Hierarchical analysis of gene diversity revealed that 99.6% of genetic variation was contained within abalone samples and only 0.4% partitioned among samples. Approximately half of the variation was accounted for by differences between abalone of the Queen Charlotte Islands/Alaska and those from central/southern BC while the other half was due to differences among samples within the two regions. Little allele frequency variation was observed among size classes or between repeat samples from sites sampled in more than one year. The results indicated that, historically, northern abalone aggregations did not represent isolated breeding units and any disruption of gene flow that may have been caused by recent low abundance levels cannot yet be detected. These results are discussed with respect to rebuilding efforts to be undertaken for northern abalone within BC.

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QUESTIONS

Q: How long would it take for isolated populations to become genetically different? Is it too soon to say whether the low numbers and high degree of isolation of local populations has made a difference?
A: That was the point of also looking at the younger abalone. If the perceived isolation was having any effect, we would see signs of reproductive failure, within a 30-year period or sooner if the failures due to the isolation were more dramatic.

REHABILITATION METHODS

A PERSPECTIVE FROM NEW ZEALAND ON ABALONE STOCK ENHANCEMENT, WITH EMPHASIS ON EARLY LIFE HISTORY.

by

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ABSTRACT

Roberts, R. 2003. A perspective from New Zealand on abalone stock enhancement, with emphasis on early life history. Can. Tech. Rep. Fish. Aquat. Sci. 2482: 77-96.

In New Zealand, abalone harvest from commercial, recreational, traditional and illegal catch is ~1700 t per year. Fishing effort is controlled by catch limits, a minimum size (125 mm shell length, SL) and method restrictions (breath-hold diving only). The total allowable commercial catch (TACC) was ~1250 t per year from 1986 until 1999. Since then, commercial catch has been reduced in several of the major fishing areas, with cuts now totaling ~14% of the 1998-99 TACC. Investigations have begun into various fishery management approaches that may provide alternatives to quota reductions. These include: (1) temporary area closures, (2) larger minimum harvest size and (3) release of juveniles or larvae. Further small-scale management initiatives have focused on better understanding the responses of so-called 'stunted stocks' to fishing. Catch-reporting has been modified to provide data at a high spatial resolution appropriate to abalone population dynamics. New Zealand enhancement trials have produced results ranging from very poor to excellent. At the best sites, economically successful enhancement was demonstrated with commercial scale releases of small abalone (averages of 9 to 15 mm SL). One of two larval reseeding trials suggested possible economic viability. New Zealand studies have highlighted the importance of suitable boulder habitat, burial by sand, and naivety of hatchery juveniles in controlling the success of reseeding. Pros and cons of reseeding abalone at various developmental stages are discussed. Releasing fertilized eggs would make sense only in areas suffering reproductive failure, or where the location or timing of release confers survival advantage to the animals. Newly metamorphosed post-larvae may be a better alternative than larval releases if problems of mortality or loss in the days after release can not be remedied. Determining the optimal size at release for larger juveniles will require site specific studies considering predation, competition and other factors. Even 2-3 mm SL juveniles are much hardier than younger juveniles and, with optimal deployment substrata, may offer a cost-effective option.

INTRODUCTION

New Zealand is one of the few countries that still has a substantial wild abalone fishery. Recent quota cuts in some areas of New Zealand have prompted renewed interest in stock enhancement and other fishery management measures. This paper first gives a brief update of abalone fishing and aquaculture in New Zealand. The paper then introduces various fishery management approaches that are currently being investigated as alternatives to further quota cuts. New Zealand abalone stock enhancement trials are summarised. Major factors that have determined their success or failure are identified, and economic viability is discussed. The remainder of the paper is devoted to a discussion of stock enhancement using various developmental stages – fertilised eggs, competent larvae, newly metamorphosed post-larvae, 2-3 mm shell length (SL) juveniles and larger juveniles. Detailed reference is made to relevant aspects of larval settlement and early juvenile feeding. Areas requiring further research are discussed along the way.

ABALONE FISHING AND AQUACULTURE IN NEW ZEALAND

New Zealand has three abalone species, all endemic. *Haliotis iris* is the largest, reaching up to 180 mm SL and represents virtually all of the commercial harvest and aquaculture production. *Haliotis australis* ($\leq$ 120 mm SL) and *Haliotis virginea* ($\leq$ 70 mm SL) occur in crevices or under boulders by day.

New Zealand abalone aquaculture is still in its infancy. There are about 25 farms operating at present, but most are only at experimental or pilot scale. Total meat production is only several tonnes per year. The intensely colored shell of *Haliotis iris* has led to strong interest in pearl production. Free pearls remain elusive, but mabe (hemispherical) pearl production is well established, and considerable effort is now going into market development (e.g., www.bluepearls.com; www.empress.co.nz). About 80 % of the 25 or so farms are land-based, flow-through operations and several are sea-based, suspended below floats. There is considerable interest in recirculating systems.

Both the commercial and recreational fisheries are controlled by catch limits, a minimum size (125 mm SL) and method restrictions (breath-hold diving only). The commercial fishery was described in detail by Schiel (1992a), so only an update is given here. The fishery now operates via two tradable property rights – an individual transferable quota (ITQ) and an Annual Catch Entitlement (ACE) (www.fishserve.co.nz). The ITQ represents the owner's share of the fishery. ITQ shares generate ACE shares, which give the holder the right to take a certain weight of abalone from a certain area. The commercial fishery was initially divided into just 8 large quota management areas (QMAs), 3 of which have negligible TACCs. Subdivision of the large QMAs into smaller reporting areas has been instigated (Fig. 1) to provide data at a spatial resolution more appropriate to the scale of population dynamics and recruitment in abalone (McShane and Smith 1991, McShane and Naylor 1995).

From 1974 until the mid-1980s the total New Zealand abalone take was controlled indirectly by a limit on the number of cans exported, translating into a catch of ~928 live-weight t per year (Murray and Akroyd 1984). However, catches were poorly controlled until the introduction of the quota management system in 1985 (Fig. 2). The total allowable commercial catch (TACC) for the New Zealand abalone fishery varied between 1238 and 1287 t per year from 1986 until 1999, and the only substantial TACC reduction was a voluntary 10% cut in one QMA in 1992. Since 1999, large (25 to 40%) catch reductions have been implemented in three major fishing areas. Together these cuts total about 14% of the 1998/99 TACC. Some further cuts are likely in the future.

In addition to commercial catch, there is significant recreational, traditional and illegal harvest. Recreational snorkellers may take 10 *Haliotis iris* and 10 *Haliotis australis* per person per day, for personal use. Estimates of recreational harvest in the 1990s (Annala et al. 2002) suggest that the national recreational take may be of the order of 200 t per year. Traditional harvest by Maori has not been quantified (Annala et al. 2002), but specific allowance of up to 15 t per year is made in some QMAs. Illegal harvest was estimated at 405 t per year in 1993/4 (Naylor et al. 1998), which was about one-third of the TACC.

MANAGEMENT MEASURES BEING INVESTIGATED

Concerns about the sustainability of abalone harvests in New Zealand have been voiced since the 1970s (Murray and Akroyd 1984). The recent catch reductions have led to renewed interest in management approaches that may prevent further cuts or enhance the fishery.

A study on Stewart Island in southern New Zealand has established 12 reporting zones of 5-10 km shoreline length. Four zones have been temporarily closed to commercial fishing, four are being harvested with an increased minimum legal size of 135 mm SL and four control zones will be fished as normal (Naylor 2002a). Reseeding trials will also be carried out in the control zones.

New Zealand has many areas where abalone do not reach minimum legal size (McShane et al. 1993, McShane et al. 1994a, Naylor 2002b). The lack of legal-sized paua in the northern half of the North Island correlates with high summer water temperatures. Stunted stocks also occur in cool waters and may arise from food limitation, high silt levels, genetics or overcrowding. A current study aims to determine whether stunted stocks can be fished sustainably (Naylor 2002b). All paua >110 mm SL have been moved from a stunted population to an area that produces legal sized abalone. Growth and length at maturity are being monitored at source, destination and unfished controls (Naylor 2002b). Results are not yet available.

OVERVIEW OF RESEEDING TRIALS IN NEW ZEALAND

Release of Larvae

Only two trials with larval release have been reported in New Zealand. Tong et al. (1987) released 300,000 12-day-old larvae to a 50 m^2 gully. Three months later minimum survival was estimated at 0.4%. At the current New Zealand price of US$500 per million larvae, the survivors had cost US$0.14 each at <4 mm SL (excluding any cost of release). This is 70%

of the cost of New Zealand hatchery seed at 10 mm SL (US$0.20 each, without the costs of release). This preliminary study suggests that larval reseeding could compete with juvenile release as a means of getting additional juvenile abalone into the fishery.

Schiel (1992b) released batches of 20,000 competent larvae within mesh tents over 1 m^2 of seafloor. Despite enclosing the larvae for 24 hours, only about 10% of larvae settled in the experimental area. Minimum survival after 5 months was 0.06% of larvae, giving a current cost of survivors of US$0.80 per juvenile based on the cost for the larvae alone. With such low survival, larval reseeding is much less cost effective than juvenile reseeding.

Release of Juveniles

The most substantial New Zealand study of juvenile abalone reseeding (Schiel 1993) produced very promising results at some of 8 sites, with the best site showing 54% survival of 10,000 3-13 mm SL seed, 23 months after release. Apparent survival was higher at 23 months than at 12 months, illustrating the difficulty in obtaining accurate survival estimates for cryptic life-stages. Projected economic returns were positive for the 3 sites with highest survival (Schiel 1993). Other New Zealand studies have produced low survival (Fig. 3). Further industry trials are currently underway.

New Zealand reseeding studies have highlighted the importance of site selection. The most suitable substratum for juvenile *Haliotis iris* is boulders overlying boulders, cobbles or pebbles (Schiel 1993, Osumi 1999). Movement of sand and rocks during storms was a major cause of mortality in each of 4 studies (Hooker 1988, Schiel 1992b, Schiel 1993, Osumi 1999). Lower survival of hatchery stock was documented in all 3 studies where it was examined (Hooker 1988, Schiel 1992b, Osumi 1999). Predator exclusion (10 mm mesh cage) had only a minor effect in 1 study, increasing survival from 60 to 75% (Schiel 1992b). The starfish *Coscinasterias calamaria* was thought to be a significant source of mortality in north-eastern New Zealand trials (Osumi 1999).

ENHANCEMENT BY RELEASE OF FERTILIZED EGGS OR LARVAE

Release of Fertilized Eggs

Enhancement of abalone populations by release of eggs or larvae is appealing because of its low cost and simplicity. The most basic model would see wild caught animals or captive broodstock spawned, and the fertilized eggs released in coastal waters. This approach to stock enhancement assumes that addition of fertilized eggs translates into additional adults, which is not proven for abalone (McShane 1995). The chances of survival being sufficient to make this strategy cost-effective can be examined by considering the success of wild spawnings. If a typical pair of abalone gives rise to say 10 million fertilized eggs in their lifetime, then a stable adult population implies that only two of those 10 million eggs survive to adulthood. Situations in which release of fertilized eggs may make sense are if:

- fishery collapse can be attributed to the Allee effect, whereby reduced adult densities negatively influence fertilisation success (Babcock and Keesing 1999);
- the location of egg release enhances survival of larvae or post-settlement stages (e.g., by preventing advection offshore, or by increasing the chances that larvae settle in ideal nursery habitat);
- the timing of egg release enhances survival of larvae or post-settlement stages (e.g., by avoiding seasons with peak predation or food competition).

Release of Competent Larvae

Larval mortality from predation, advection away from suitable habitats, or starvation is poorly described, but likely to be high (McShane 1992, 1995). Further, it is impossible to accurately assess the success of egg releases because the location of the survivors is unknown. To reduce these problems, most tests of larval release have used competent larvae rather than fertilized eggs or young larvae.

The behaviour of larvae after release will be influenced by their developmental state. The attainment of larval "competence" makes larvae capable of settling, but does not imply that they are keen to settle. Larvae become increasingly responsive to metamorphosis cues as they age (Barlow 1990, Degnan and Morse 1995), so older larvae are more likely to metamorphose close to the point of release.

Judging metamorphic competence requires care. Larvae are capable of crawling before they become competent to metamorphose (Barlow 1990). For example, *Haliotis iris* larvae reared at 17°C can crawl from 4 to 5 days old, but most will not metamorphose until 8 to 9 days old (6 or more rows of chitinised teeth in the larval radula). The Effective Accumulative Temperature (EAT) required for metamorphic competence in *Haliotis discus hannai* (Hahn 1989) does not apply to *Haliotis iris* (author's unpublished data). Morphological indicators (radula development or appearance of the 4th tubercle on cephalic tentacles) are more likely to transfer between species, but should not be applied uncritically.

Crustose coralline algae are among the most effective settlement-inducers for all abalone species tested to date (Roberts 2001a), so suitable habitat with coralline cover is the logical target for larval releases. Certain species of coralline can be more favorable than others for abalone larval settlement (Daume et al. 1999, Roberts 2001b) or post-larval survival (Day and Branch 2000). Despite the effectiveness of corallines as settlement cues, competent abalone larvae often resume swimming after landing on corallines, particularly less preferred coralline species (Roberts 2001b). In studies of stock enhancement by larval release, resumption of swimming could lead to rapid transport out of the study area, with consequences for estimates of survival. This issue could be minimized by priming larvae to settle with soluble chemicals prior to release (Roberts and Nicholson 1997) or by using older larvae.

Abalone larvae are lecithotrophic, and traditionally assumed to have short period of potential dispersal (McShane 1992). Recent research shows that abalone larvae can metamorphose successfully after lengthy periods - *Haliotis iris* after 26 d at 17°C (Roberts and Lapworth 2001), *Haliotis discus hannai* after 19 days at 20°C (Takami et al. 2002). Given that larval development is temperature dependent, abalone that spawn in cold water will experience extension of both the pre-competent and competent larval phases. For example, assuming that *Haliotis iris* larvae have a biological zero point of 5°C (calculated from Tong et al. 1992) and that development is proportional to temperature between 5 and 17°C, then larvae growing in 10°C water would take ~18 days to reach metamorphic competence, and may metamorphose successfully after 60 days. Thus potential dispersal periods can be quite lengthy in extreme circumstances, but this does not preclude localized recruitment (Prince et al. 1987).

Causes of Mortality of Released Larvae

Previous studies of larval release have documented very high mortality or loss of abalone soon after release. Schiel (1992b) found that only 10% of larvae "settled" and Preece et al. (1997) reported survival rates of 0.4 to 6.5% after 6 days. The use of mesh tents to retain larvae for 1 to 6 days in these studies suggests that larval advection offsite is unlikely to have been a major factor. This containment approach will be impractical at commercial scale, but chemically priming larvae to settle prior to release should be possible. Post-larval abalone survive and grow for a week or so after metamorphosis without food (Takami et al. 2000, Roberts et al. 2001) but food limitation could make post-larvae more susceptible to other causes of mortality. Predation (Morse et al. 1979, Naylor and McShane 1997a) and dislodgment by waves (Naylor and McShane 1997b) can cause major mortality of newly settled post-larvae. Both could be minimized by careful site selection. Avoidance of predators will require attention to the types of coralline algae present, as some growth forms harbor predatory polychaete worms (e.g., McShane 1996). Entanglement on diatom films or other sticky surfaces could also affect survival of settling larvae (Kawamura and Kikuchi 1992, Roberts 2001b).

The issue of distinguishing released stock from natural recruits is most problematic for eggs, larvae and post-larvae. Larval and post-larval shells could probably be marked by bath application of a fluorescent marker such as tetracycline (Pirker and Schiel 1993), rare earth elements (Levin et al. 1993) or establishment of a geochemical signature for hatchery spat. However, the larval and post-larval shell may be eroded or overgrown at a relatively early age. Shell marking is not an option for fertilized eggs, so a couple of days of larval rearing would be required to mark the shell. Genetic markers (e.g., Evans et al. 1999, Huang et al. 2000) may be the optimal solution for release of very early life stages. To make these methods affordable, random samples of juveniles seen during censuses could be analysed to establish ratios of seeded to wild stock.

ENHANCEMENT BY RELEASE OF JUVENILES

Where Should Enhancement Efforts be Targeted?

Hilborn (1998) warned that stock enhancement returns would be minimal if there were strong density-dependent mortality at some stage after release. It follows that stock enhancement by release of juveniles has the greatest potential in areas that previously had good recruitment and strong fisheries, but where recruitment has failed due to stock reduction (e.g., by overfishing). Hilborn's (1998) suggestion that the most cost-effective remedy is a reduction in fishing pressure is less relevant for abalone than for mobile and resilient species. Abalone adults are relatively sedentary, their recruitment can be localised (e.g., McShane et al. 1988, McCormick et al. 1994), and abalone populations have a poor record of rebuilding following severe stock reduction (e.g., Campbell 2000).

While some New Zealand abalone stocks have been reduced to the point where catch reductions are required to protect the future of the fishery, there is no documented evidence of recruitment failure induced by stock reduction. The interest in reseeding is therefore largely in enhancing the production from existing stocks, rather than to recover from fishing-induced recruitment failure. This approach assumes that reseeding can potentially increase the yield from the fishery wherever the environment has spare capacity to support additional animals from the age of reseeding to harvest. Most New Zealand abalone stocks now carry a fraction of the virgin biomass of adult animals, implying substantial capacity for expansion of adult stocks (acknowledging that growth and survival rate may decline, and competing grazers may be compromised). A critical issue is whether the fishery is recruitment-saturated. If not, then the release of juveniles could translate into additional adults in the fishery.

I use the term "recruitment-saturated" rather than "recruitment-limited" to put a different slant on interpretation of recruitment patterns. If we look at a fishery with strong regular recruitment, we may tend to assume that it is not recruitment-limited. However, unless some stage of the life cycle experiences strong and consistent density-dependent mortality then there is potential to increase the number of adults by increasing the number of recruits.

While there is some evidence in favour of density-dependent mortality in early life-stages of abalone (McShane 1991, Sasaki and Shepherd 1995, Preece et al. 1997, Shepherd et al. 2000), the limited New Zealand evidence is to the contrary (Schiel 1993). Overall little is known about the prevalence or intensity of density-dependent mortality in abalone. What proportion of habitat is affected, and is the effect consistent between years? How does the density dependence vary with the fortunes of competing species? Is the effect so strong that addition of larvae or seed abalone is not economically viable?

If we assume that sites with regular recruitment are recruitment-saturated then we risk turning our backs on habitats that may offer good prospects for reseeding. Rather than attempting to understand complex issues of density-dependent mortality and carrying capacity in advance of reseeding it may be more productive to examine them as part of reseeding trials.

While abalone recruitment remains strong in many New Zealand abalone populations, others naturally have very low levels of recruitment (McShane 1993, McShane et al. 1994b). The latter are characterised by accumulations of large adults and a paucity of juveniles. They typically occur in extremely wave-exposed sites (McShane 1993, McShane et al. 1994b), where juvenile habitat is limited, or is disturbed so often that survival of juveniles is rare. Recruitment most likely occurs in spatial refuges sheltered from prevailing conditions, with emergent abalone migrating to adult beds. The alternative explanation of episodic recruitment is less plausible given that a sufficient period without major storms is very unlikely. These low recruitment sites offer poor prospects for enhancement unless suitable, "storm-proof" habitat can be found or created.

Competition for Food Resources in Juvenile Abalone Habitat

Crustose coralline algae are a poor food source for abalone post-larvae relative to diatom films (Kawamura et al. 1998). Diatom densities on corallines are typically very low and bacterial densities highly variable (Johnson et al. 1991, Roberts 2001b). The carrying capacity of corallines for young abalone will be modest, and this should be taken into account when deciding release densities in larval or post-larval reseeding. Visible signs of starvation have been described from laboratory studies (Roberts et al. 2001) and reported in post-larvae from natural habitat at densities of up to a few hundred newly settled post-larvae per m^2 (Sasaki and Shepherd 2001). Maximum densities of abalone post-larvae reported from field studies are wildly variable, ranging from less than 1 to over 12,000 per m^2 of seafloor (McShane and Smith 1991, McShane et al. 1994c, Prince and Ford 1985, Sasaki and Shepherd 1995, Shepherd 1998, Sasaki and Shepherd 2001). Shepherd et al. (2000) suggested a post-larval carrying capacity of ~100 m^{-2} in a South Australian habitat, comparable to Sasaki and Shepherd's (2001) estimate of ~200 m^{-2} in Japan.

A large proportion of corallines' carrying capacity will be taken by other marine invertebrates. The competitors will change as the abalone develops physically and behaviourally (Table 1). As small post-larvae (< 0.8 mm SL), abalone are relatively feeble grazers. Their radula has strongly re-curved teeth apparently suited to scooping loosely attached material from surfaces (Roberts et al. 1999, Kawamura et al. 2001). These small post-larvae will compete with all grazers that remove diatom cells, other loose biofilm material and coralline exudates. These include crustaceans, archaeogastropods, urchins and chitons. As larger post-larvae (> 0.8 mm SL) abalone can access grazing resistant diatoms such as *Cocconeis* spp., which are commonly dominant on heavily grazed surfaces (Kawamura et al. 1998). Between 1 and 2 mm SL, further lateral teeth are added to the radula with 3 pairs becoming specialised as gouging teeth (Roberts et al. 1999, Kawamura et al. 2001). Observations of coralline thallus in gut contents of 5 to 10 mm SL abalone (Shepherd and Cannon 1985) defy Steneck and Watling's (1982) classification of abalone as grazers incapable of eating corallines. This superior grazing ability will give a reduced set of competitors, which will include chitons, limpets and urchins.

Moving water stimulates a drift feeding posture in some abalone species. The abalone raises the anterior end of its shell and holds two extensions of the foot up in front of the shell. Tactile stimulation of these extensions or the epipodium results in rapid movement to capture the "drift algae" with the extensions of the foot. Captive *Haliotis iris* are apparently undiscriminating, and will happily "capture" a human finger, draw it under their snout and begin grazing on it (R. Roberts pers. obs.). Drift feeding behaviour appears to develop at about 5 mm SL in captive *Haliotis iris*. When touched with filamentous algae, animals $\geq$ 5 mm SL typically attempt to capture the food, while smaller abalone either flee or clamp down (R. Roberts pers. obs.). Drift feeding behaviour has also been observed in wild juvenile *H. laevigata* and *H. scalaris* (Shepherd and Cannon 1985). The dietary shift of the latter species implies drift feeding at sizes $\geq$ 10 mm SL. Juveniles may catch drift algae that enters their cryptic habitat during daylight, and graze actively at night. The trapping of drift algae is a behavioural specialization that offers abalone a feeding niche with reduced competition (predominantly from urchins). It also opens up a potentially large food source from beyond the home range of the abalone.

What Size of Juvenile Abalone to Release?

An informed answer to this question requires information on the size-dependence of mortality in the site to be reseeded. This information is best gained from local reseeding trials, as size-related population bottlenecks are likely to be highly site-specific, depending on the local substratum, hydrodynamics, predators and food supply for the various life stages.

If "drift" feeding reduces the range of competing grazers, and opens up an additional food supply (see above), then the most intense food competition may occur when abalone are < 5 to 10 mm SL. Shepherd and Daume (1996) suggested that available shelter was almost certainly a limiting factor for the cryptic juvenile stages of abalone. This competition for space would be most intense among large cryptic juveniles as each animal occupies more surface area at rest, and larger animals lose access to finer spaces. Clearly, a theoretical consideration of possible survival bottlenecks quickly leads to uncertain conclusions, supporting the need for site specific field studies.

Post-larvae may offer a viable, low-cost option that overcomes the problems encountered with major early mortality or loss of larvae (Schiel 1992b, Preece et al. 1997). One logical option is to deploy abalone just a few days after settlement, to ensure metamorphosis has occurred while minimising cost. Expectations of survival should be realistic. Even in the protected environment of a hatchery, survival from larva to a few months of age is typically below 10%. Much higher mortality rates occur in natural habitats (Shepherd and Daume 1996). Another option is to deploy abalone at 2-3 mm SL because juveniles in hatcheries appear to become much less susceptible to major mortality episodes at ~ 2 mm SL (Roberts et al. 1998). To optimise survival of post-larvae, the post-larvae could be deployed on habitats with a complex surface that provides refuge from most predators, and a large surface area seeded with an ideal food such as the grazing-resistant green alga, *Ulvella lens*. Alternatively, the post-larvae can be anaesthetised and "hosed" onto the seafloor in a similar fashion to larvae (Preece et al. 1997).

If releasing larger juveniles, the choice of seed size is a compromise between the increasing cost and greater survival of larger seed. Many studies have documented higher survival of larger seed, with some indication of an optimum at 30 to 40 mm SL (e.g., Tegner and Butler 1985, McCormick et al. 1994). However, some successes with small seed have been reported. For example, Schiel's (1993) best site received the smallest seed (mean 9 mm SL).

Estimates of diver efficiency in detecting released juvenile abalone in cryptic habitat range from 13% to 70% (Tanaka et al. 1991, Preece et al. 1997, Shepherd 1998, Seki and Taniguchi 2000) and smaller abalone are usually more difficult to detect (Schiel 1993, Shepherd 1998). Thus, the apparent higher survival of larger seed is probably partly an artefact of easier detection by divers. Repeat surveys, preferably with individually labelled seed, could be used to estimate the extent of this artefact.

Minimising Naive Behaviour of Hatchery-Reared Seed

Hatchery seed commonly show naive behaviour and lower survival than wild counterparts (e.g., Schiel and Welden 1987, McCormick et al. 1994, Osumi 1999). Naive behaviour is a likely cause of the high mortality often documented in the first days to weeks after release (e.g., Fig. 3). The naivety probably results from the protected, artificial environment of the hatchery (e.g., Schiel and Welden 1987), but could also be a ubiquitous feature of abalone that is erased from natural populations by early mortality of the naive individuals. There is some evidence that hatchery reared abalone acclimate to new environments within several days, implying potential to improve the behaviour of seed abalone (Schiel and Welden 1987).

If naive behaviour is a function of the hatchery environment, then opportunity exists to "train" abalone to exhibit appropriate behaviour. Farmers could provide shelters to maintain the cryptic habit of light-sensitive juveniles. Strong light: dark cycles and night–time feeding may encourage the maintenance of nocturnal behaviour. Periodic exposure to predators or their odours may help develop and maintain appropriate predator avoidance behaviour – an approach that has been effective with juvenile salmon (Olla et al. 1998). Anti-predator training should target the major threats at the site in question, and is more likely to be effective against slow moving predators such as starfish than against highly mobile predators like octopus, crabs or finfish.

CLOSING REMARKS

The motivation to establish commercially viable abalone reseeding in New Zealand is stronger than ever. The increasing number of successful experiments in recent years (e.g., Seki and Taniguchi 2000, de Waal 2001, C. D. Dixon et al. personal communication, University of Melbourne) and Schiel's (1993) demonstration of excellent survival in commercial scale trials in New Zealand show that it can be done. The challenge is to identify parameters that give good survival with sufficient consistency to make the overall operation economically rewarding. While several major ingredients of the recipe are already known, others will require site specific trials to determine local importance.

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REFERENCES

Annala, J.H., K.J. Sullivan, C.J. O'Brien, and S.D. Iball (Compilers). 2002. Report from the fishery assessment plenary, May 2002: stock assessments and yield estimates. Ministry of Fisheries. Wellington.

Babcock, R. and J. Keesing. 1999. Fertilization biology of the abalone *Haliotis laevigata*: laboratory and field studies. Can. J. Fish. Aquat. Sci. 56: 1668-1678.

Barlow, L.A. 1990. Electrophysiological and behavioural responses of larvae of the red abalone (*Haliotis rufescens*) to settlement-inducing substances. Bull. Mar. Sci. 46: 537-554.

Campbell, A. 2000. Review of northern abalone, *Haliotis kamtschatkana*, stock status in British Columbia. Can. Spec. Publ. Fish. Aquat. Sci. 130: 41-50.

Daume, S., S. Brand-Gardner, and Wm. J. Woelkerling. 1999. Settlement of abalone larvae (*Haliotis laevigata* Donovan) in response to non-geniculate coralline red algae (Corallinales, Rhodophyta). J. Exp. Mar. Biol. Ecol. 234: 125-143.

Day, L. and G.M. Branch. 2000. Relationships between recruits of the abalone *Haliotis midae*, encrusting corallines and the sea urchin *Parechinus angulosus*. S. Afr. J. Mar. Sci. 22: 137-144.

Degnan, B.M. and D E. Morse. 1995. Developmental and morphogenetic gene regulation in *Haliotis rufescens* larvae at metamorphosis. Amer. Zool. 35: 391-398.

de Waal, S., and P. Cook. 2001. Quantifying the physical and biological attributes of successful ocean seeding sites for farm-reared juvenile abalone, *Haliotis midae*. J. Shellfish Res. 20: 857-861.

Evans, B.S., N.G. Elliott, and R.W.G. White. 1999. Microsatellite DNA markers for abalone culture. World Aquaculture 99 Book of Abstracts: 247.

Hahn, K.O. 1989. Larval development of abalone, p. 71-99. In K. O. Hahn [ed]. Handbook of Culture of Abalone and Other Marine Gastropods.. CRC Press, Boca Raton.

Hilborn, R. 1998. The economic performance of marine stock enhancement projects. Bull. Mar. Sci. 62: 661-674.

Hooker, S.H. 1988. The demography of paua (*Haliotis iris*) with special reference to juveniles. MSc. Thesis. University of Auckland.

Huang, B.X., R. Peakall, and P.J. Hanna. 2000. Analysis and genetic structure of blacklip abalone (*Haliotis rubra*) populations using RAPD, minisatellite and microsatellite markers. Mar. Biol. 136: 207-216.

Johnson, C.R., D G. Muir, and A.L. Reysenbach. 1991. Characteristic bacteria associated with surfaces of coralline algae: a hypothesis for bacterial induction of marine invertebrate larvae. Mar. Ecol. Prog. Ser. 74: 281-294.

Levin, L. A., D. Huggett, P. Myers, T. Bridges and J. Weaver. 1993. Rare-earth tagging methods for the study of larval dispersal by marine invertebrates. Limnol. Oceanogr. 38: 346-360.

Kawamura, T. and S. Kikuchi. 1992. Effects of benthic diatoms on settlement and metamorphosis of abalone larvae. Suisanzoshoku 40: 403-409.

Kawamura, T., R.D. Roberts, and H. Takami. 1998. A review of the feeding and growth of post-larval abalone. J. Shellfish Res. 17: 615-625.

Kawamura, T., H. Takami, R.D. Roberts, and Y. Yamashita. 2001. Radula development in abalone *Haliotis discus hannai* from larva to adult in relation to transitions in feeding. Fisheries Sci. 67: 596-605.

McCormick, T.B., K. Herbinson, T.S. Mill, and J. Altick. 1994. A review of abalone seeding, possible significance and a new seeding device. Bull. Mar. Sci. 55: 680-693.

McShane, P.E. 1991. Density-dependent mortality of recruits of the abalone *Haliotis rubra* (Mollusca: Gastropoda). Mar. Biol. 110: 385-389.

McShane, P.E. 1992. Early life history of abalone: a review, p. 120-138. In S. A. Shepherd, M.J. Tegner and S.A. Guzmán del Próo [eds.] Abalone of the World: Biology, Fisheries and Culture. Fishing News Books, Oxford.

McShane, P.E. 1993. Evidence for localised recruitment failure in the New Zealand abalone *Haliotis iris* (Mollusca : Gastropoda), p. 145-149. In C.N. Battershill, D.R. Schiel, G.P. Jones, R.G. Creese and A.B. MacDiarmid [eds.]. Proceedings of the Second International Temperate Reef Symposium. NIWA. Wellington.

McShane, P.E. 1995. Recruitment variation in abalone: its importance to fisheries management. Mar. Freshwater Res. 46: 555-570.

McShane, P E. 1996. Recruitment processes in abalone (*Haliotis* spp.). p. 315-324. In Y. Watanabe, Y. Yamashita and Y. Oozeki [eds.]. Survival Strategies in Early Life Stages of Marine Resources. A. A. Balkema. Rotterdam.

McShane, P.E. and J.R. Naylor. 1995. Small-scale spatial variation in growth, size at maturity, and yield- and egg-per-recruit relations in the New Zealand abalone *Haliotis iris*. N.Z. J. Mar. Fresh. Res. 29: 603-612.

McShane, P.E. and M.G. Smith. 1991. Recruitment variation in sympatric populations of *Haliotis rubra* (Mollusca : Gastropoda) in southeast Australian waters. Mar. Ecol. Prog. Ser. 73: 203-210.

McShane, P.E., K.P. Black, and M.G. Smith. 1988. Recruitment processes in *Haliotis rubra* (Molluscs: Gastropoda) and hydrodynamics in south-eastern Australia imply localized dispersal of larvae. J. Exp. Mar. Biol. Ecol. 124: 174-203.

McShane, P., S. Mercer, and R. Naylor. 1993. An update on PAU 7 stocks. New Zealand Professional Fisherman 7(6): 37-40.

McShane, P., S. Mercer, and R. Naylor. 1994a. Paua - surveys off the Otago coast and studies of stunted stocks. Seafood New Zealand 2(5): 34-36.

McShane, P., P. Notman, J. Kapa, and R. Welsh. 1994b. Surveys of paua stocks - West Coast, South Island (Northern part). Seafood New Zealand 2(1): 57-58.

McShane, P.E., S.F. Mercer, J.R. Naylor, and P.R. Notman. 1994c. Paua (*Haliotis iris*) fishery assessment 1994. NZ Fisheries Assessment Res. Doc. 94/16. MAF Fisheries, Wellington.

Morse, D.E., N. Hooker, L. Jensen, and H. Duncan. 1979. Induction of larval abalone settling and metamorphosis by γ-aminobutyric acid and its congeners from crustose red algae: II: Applications to cultivation seed-production and bioassays; principle causes of mortality and interference. Proc. World Mariculture Soc. 10: 81-91.

Murray, T. and J.M. Akroyd. 1984. The New Zealand paua fishery: an update of biological considerations to be reconciled with management goals. Fish. Res. Centre Int. Rep. No. 5. Fisheries Research Division. Wellington.

Naylor, R. 2002a. Enhancing paua fisheries. Fisheries and Aquaculture Update No. 5. National Institute of Water and Atmospheric Research. Wellington.

Naylor, R. 2002b. Fishing stunted paua stocks. Fisheries and Aquaculture Update No. 5. National Institute of Water and Atmospheric Research. Wellington.

Naylor, J.R. and P.E. McShane. 1997a. Predation by polychaete worms on larval and post-settlement abalone *Haliotis iris* (Mollusca: Gastropoda). J. Exp. Mar. Biol. Ecol. 214: 283-290.

Naylor, J.R. and P.E. McShane. 1997b. Post-settlement survival of abalone (*Haliotis iris, H. australis*) in turbulent flows. Moll. Res. 18: 227-232.

Naylor, J.R., P.R. Notman, S.F. Mercer, and P. Gerring. 1998. Paua *(Haliotis iris)* fishery assessment in PAU 5, 6 and 7. New Zealand Fisheries Assessment Research Document 98/5. Ministry of Fisheries, Wellington.

Olla, B.L., M.W. Davis, and C.H. Ryer. 1998. Understanding how the hatchery environment represses or promotes the development of behavioural survival skills. Bull. Mar. Sci. 62: 531-550.

Osumi, K. 1999. Stock enhancement and habitat association of juvenile paua *(Haliotis iris)* in north-eastern New Zealand. MSc. Thesis. University of Auckland.

Pirker, J.G., and D.R. Schiel. 1993. Tetracycline as a fluorescent shell-marker in the abalone *Haliotis iris*. Mar. Biol. 116: 81-86.

Preece, P., S.A. Shepherd, S.M. Clarke, and J.K. Keesing. 1997. Abalone stock enhancement by larval reseeding: effect of larval density on settlement and survival. Moll. Res. 18: 265-274.

Prince, J.D. and W.B. Ford. 1985. Use of anaesthetic to standardize efficiency in sampling abalone populations (Genus *Haliotis*; Mollusca: Gastropoda). Aust. J. Mar. Fresh. Res. 36: 701-706.

Prince, J.D., T.L. Sellers, W.B. Ford, and S.R. Talbot. 1987. Experimental evidence for limited dispersal of haliotid larvae (genus *Haliotis*; Mollusca: Gastropoda). J. Exp. Mar. Biol. Ecol. 106: 243-263.

Roberts, R.D. 2001a. A review of settlement cues for larval abalone (*Haliotis* spp.). J. Shellfish Res. 20: 571-587.

Roberts, R.D. 2001b. Factors affecting larval settlement and post-larval performance of New Zealand abalone, *Haliotis* spp. PhD Thesis. University of Otago.

Roberts, R.D. and C. Lapworth. 2001. Effects of delayed metamorphosis on larval competence, and post-larval survival and growth, in the abalone *Haliotis iris* Gmelin. J. Exp. Mar. Biol. Ecol. 258: 1-13.

Roberts, R.D. and C.M. Nicholson. 1997. Variable response from abalone larvae (*Haliotis iris, H. virginea*) to a range of settlement cues. Moll. Res. 18: 131-141.

Roberts, R.D., R. Searcy-Bernal, and P.A. Cook. 1998. A workshop on the culture of larval and post-larval abalone. Third International Abalone Symposium. October 26-31. Monterey, California, USA. *Cawthron Report* No. 477.

Roberts, R.D., T. Kawamura, and H. Takami. 1999. Morphological changes in the radula of abalone (*Haliotis iris*) during post-larval development. J. Shellfish Res. 18: 637-644.

Roberts, R.D., C. Lapworth, and R.J. Barker. 2001. Effect of starvation on the growth and survival of post-larval abalone (*Haliotis iris*). Aquaculture 200: 323-338.

Sasaki, R. and S.A. Shepherd. 1995. Larval dispersal and recruitment of *Haliotis discus hannai* and *Tegula* spp. on Miyagi coasts, Japan. Mar. Freshwater Res. 46: 519-529.

Sasaki, R. and S.A. Shepherd. 2001. Ecology and post-settlement survival of the ezo abalone, *Haliotis discus hannai*, on Miyagi coasts, Japan. J. Shellfish Res. 20: 619-626.

Schiel, D.R. 1992a. The paua (abalone) fishery of New Zealand, p. 427-437. In S.A. Shepherd, M.J. Tegner and S.A. Guzmán del Próo [eds.]. Abalone of the World: Biology, Fisheries and Culture. Fishing News Books, Oxford.

Schiel, D.R. 1992b. The enhancement of paua (*Haliotis iris* Martyn) populations in New Zealand, p. 474-484. In S A. Shepherd, M.J. Tegner and S.A. Guzmán del Próo [eds.]. Abalone of the World: Biology, Fisheries and Culture. Fishing News Books, Oxford.

Schiel, D.R. 1993. Experimental evaluation of commercial-scale enhancement of abalone *Haliotis iris* populations in New Zealand. Mar. Ecol. Prog. Ser. 97: 167-181.

Schiel, D.R. and B.C. Welden. 1987. Responses to predators of cultured and wild red abalone, *Haliotis rufescens,* in laboratory experiments. Aquaculture 60: 173-188.

Seki, T. and K. Taniguchi. 2000. Rehabilitation of northern Japanese abalone, *Haliotis discus hannai*, populations by transplanting juveniles. Can. Spec. Publ. Fish. Aquat. Sci. 130: 72-83.

Shepherd, S A. 1998. Studies on southern Australian abalone (Genus *Haliotis*) XIX: long term juvenile mortality dynamics. J. Shellfish Res. 17: 813-825.

Shepherd, S.A. and J. Cannon. 1985. Studies on southern Australian abalone (genus *Haliotis*): X) Food and feeding of juveniles. J. Malac. Soc. Aust. 9: 21-26.

Shepherd, S.A. and S. Daume. 1996. Ecology and survival of juvenile abalone in a crustose coralline habitat in South Australia, p. 297-313. In Y. Watanabe, Y. Yamashita and Y. Oozeki [eds.]. Survival Strategies in Early Life Stages of Marine Resources. A. A. Balkema. Rotterdam.

Shepherd, S.A., P.A. Preece, and R.W.G. White. 2000. Tired nature's sweet restorer? Ecology of abalone (*Haliotis spp.*) stock enhancement in Australia. Can. Spec. Publ. Fish. Aquat. Sci. 130: 84-97.

Steneck, R. S. and L. Watling. 1982. Feeding capabilities and limitation of herbivorous molluscs: a functional group approach. Mar. Biol. 68: 299-319.

Takami, H., T. Kawamura, and Y. Yamashita. 2000. Starvation tolerance of newly metamorphosed abalone *Haliotis discus hannai*. Fisheries Sci. 66: 1180-1182.

Takami, H., T. Kawamura, and Y. Yamashita. 2002. Effects of delayed metamorphosis on larval competence, and post-larval survival and growth of abalone *Haliotis discus hannai*. Aquaculture 213: 311-322.

Tanaka, E., H. Yamakawa, S. Yamada, M. Nonaka, and A. Hasegawa. 1991. A method for estimating mortality rate and divers' sighting rate for tagged abalones. Nippon Suisan Gakkaishi 57: 189-194.

Tegner, M.J. and R.A. Butler. 1985. The survival and mortality of seeded and native red abalones, *Haliotis rufescens*, on the Palos Verdes Peninsula. Calif. Fish and Game 71: 150-163.

Tong, L.J., G.A. Moss, and J. Illingworth. 1987. Enhancement of a natural population of the abalone, *Haliotis iris*, using cultured larvae. Aquaculture 62: 67-72.

Tong, L.J., G.A. Moss, P. Redfearn, and J. Illingworth. 1992. A manual of techniques for culturing paua, *Haliotis iris*, through to the early juvenile stage. New Zealand Fisheries Tech. Report No. 31.

Table 1. Size-related transitions in the feeding biology of juvenile abalone.

Shell length (mm)	Radula characteristics [1] and feeding behaviour	Foods [2]	Competitors for food [3]
0.3 to 0.8	Delicate, re-curved radula teeth that scoop up loosely attached material. Marginal teeth proliferating. Feeding day and night.	Bacteria, loose diatoms, coralline cuticle and epithallus, trail mucus.	All grazers on corallines (archaeogastropods, chitons, crustaceans, urchins).
0.8 to 5.0 tightly	Additional lateral teeth specialised for gouging. Gap between adjacent rows of teeth widens to handle larger particles. Feeding day and night.	Tightly attached diatoms and other algae, macroalgal germlings, colonial/stalked diatoms, biofilm and secretions on corallines.	Reduced competition from gastropods and crustaceans unable to ingest attached diatoms and macroalgae. Still competes with limpets, chitons and urchins.
> 5.0 (limpets,	Advent of drift feeding behaviour and light sensitivity. Emerge to graze at night. May "drift feed" in cryptic habitat by day.	Drifting seaweed and seagrass. Coralline thallus. Biofilm and secretions on corallines and other surfaces.	Reduced competition for drift food (urchins) and coralline thallus chitons and urchins).

Key references: [1] Roberts et al. (1999), Kawamura et al. (2001), [2] Kawamura et al. (1998), [3] Steneck and Watling (1982).

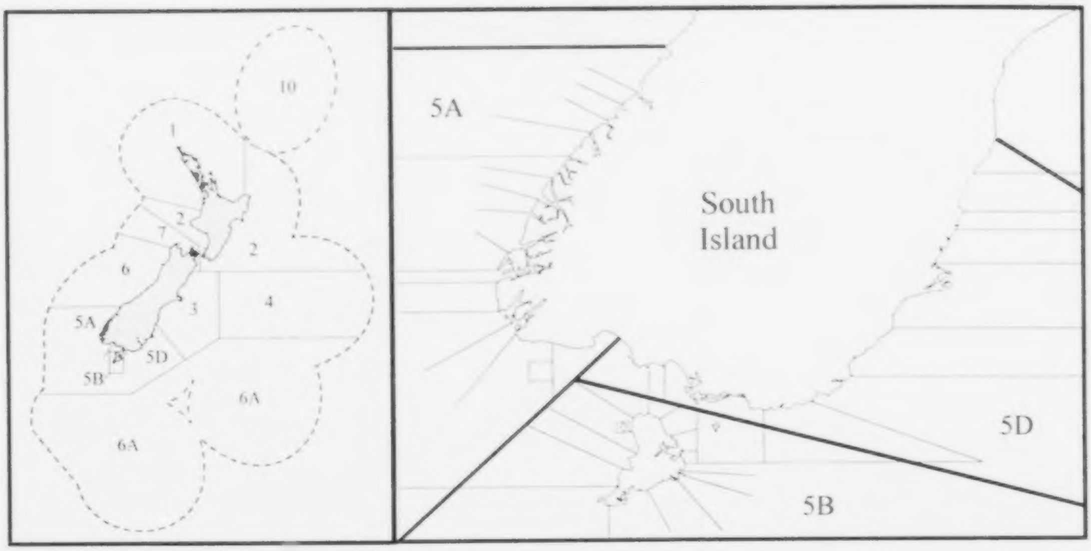
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Figure 1. The New Zealand abalone fishery is subdivided into large Quota Management Areas (left). Smaller reporting zones have been established to provide high-resolution information on catch and catch per unit effort. An example from southern New Zealand is shown (right).

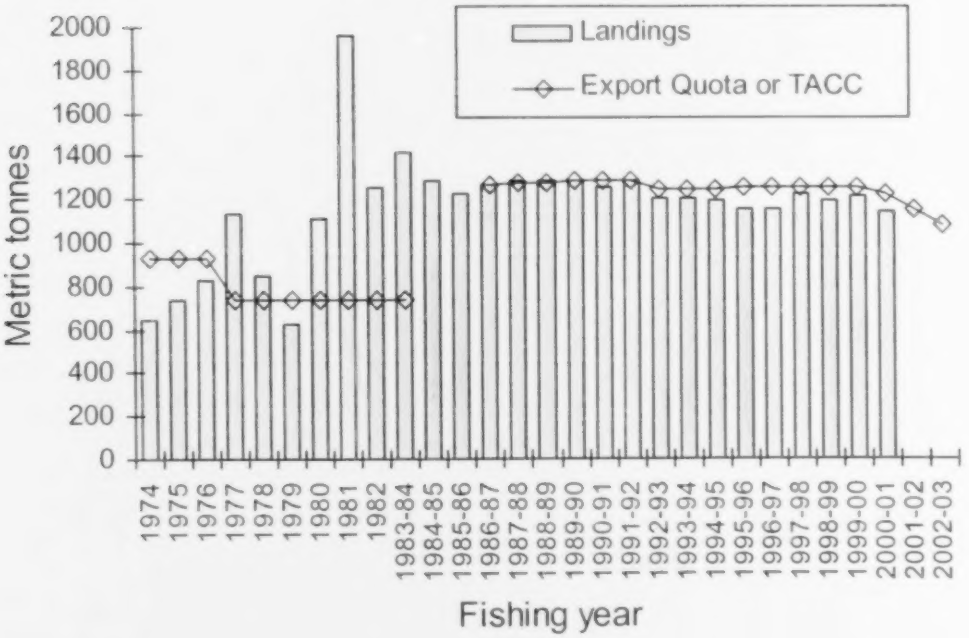

Figure 2. Catch (columns) and catch limits (line) by year in the New Zealand abalone fishery. Prior to 1986, the catch limit was set by an Export Quota restricting the number of cans exported. Subsequently, Total Allowable Commercial Catches (TACCs) were introduced as part of the Quota Management System. Fishing years differed from calendar years from 1983.

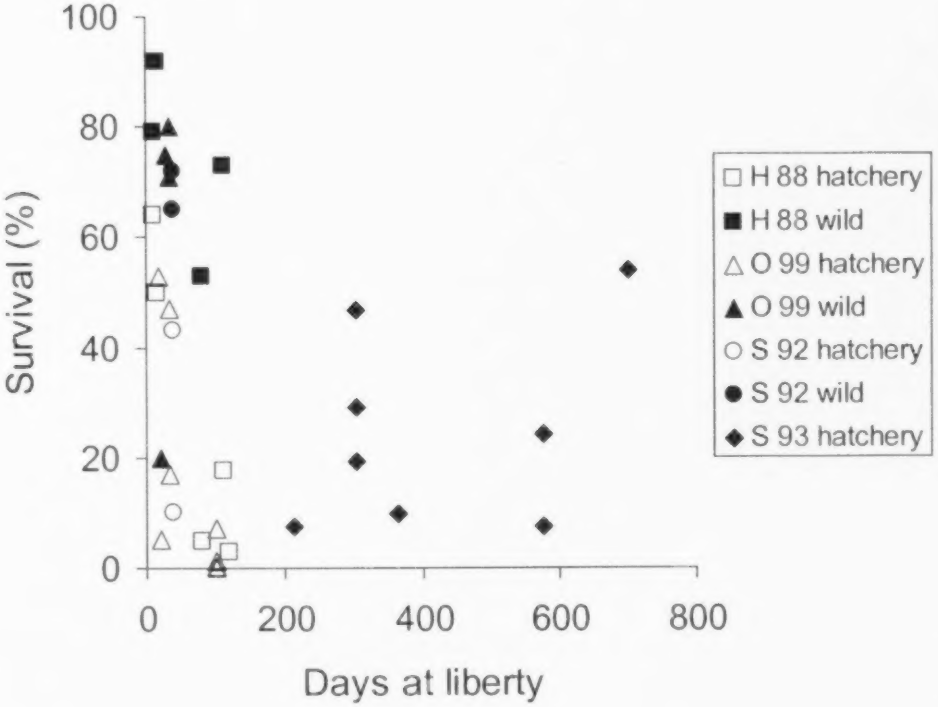

Figure 3. Survival as a function of time at liberty for juvenile abalone released in New Zealand reseeding trials. H88 = Hooker (1988) using data for tagged hatchery-reared abalone and untagged wild abalone; O 99 = Osumi (1999) where both wild and hatchery-reared abalone were tagged; S 92 = Schiel (1992b); S 93 = Schiel (1993). Hatchery = hatchery-reared seed (closed symbols). Wild = juveniles taken from the wild (open symbols).

QUESTIONS

Q: Are there any management techniques on how the animals are produced for reseeding?
A: Reseeding is still at trial stage in New Zealand. Protocols are currently being put in place to control risks from diseases, pests and genetic contamination. Hatcheries have begun treating seed in ways that should help them behave appropriately after release.

Q: What was the diet fed the small juveniles?
A: Some farmers grind up manufactured abalone feeds and add the powder to tanks with post-larvae as small as 1-2 mm shell length. Microencapsulated diets have recently been tested in small scale experiments in Japan. The green alga *Ulvella lens*, is becoming popular in several countries. Its main role is to provide a grazing-resistant food source that is not completely removed by grazing.

A REVIEW OF ABALONE ENHANCEMENT AND REHABILITATION IN SOUTH AFRICA [ABSTRACT].

by

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ABSTRACT

Cook, P. 2003. A review of abalone enhancement and rehabilitation in South Africa [Abstract]. Can. Tech. Rep. Fish. Aquat. Sci. 2482: 97-100.

The South African coastline is approximately 3,000 km long with very few bays, inlets or sheltered areas. The exposed coastline limits opportunities for mariculture. However, the commercial harvest of abalone is threatened by a high level of illegal poaching and this situation has provided support for a very successful farming industry for *Haliotis midae*. Abalone farming has expanded rapidly in South Africa and, by 2004, annual production is expected to exceed 600 tonnes per year. Most farms have hatcheries and this leads to excess production of juveniles that could be used for enhancement or ranching. Wild populations, consisting of six species of abalone, occur on the southwest, south and southeast coasts of South Africa. Although the west coast is a highly productive area with extensive kelp beds and high wave action, abalone occur naturally only in the southernmost sections.

Experiments to determine the feasibility of abalone enhancement and ranching in South Africa were carried out at Port Nolloth, on the northwest coast. This site was chosen due to the presence of abalone fossils, the presence of high densities of urchins – both indicating appropriate environmental conditions for abalone - and the availability of security from a diamond mine in the vicinity. The site was over 300 km from any natural abalone population, assuring that any animals in the area were from the ranching experiments.

Anticipated problems with the sea ranching included release mechanisms that could cause mortalities, predation after release, monitoring success (% survival), and assessing economic viability. To reduce the mortality caused by handing during the transportation and release of abalone, special release mechanisms were devised. These devises consisted of PVC pipes halved lengthwise and glued to a Perspex sheet. Both ends of the PVC covered with mesh

after the abalone entered the devices naturally. The devices were transferred intact without handling the individual animals. The devices were attached to concrete blocks at the experimental site in the late afternoon. Twenty four hours later, the mesh was removed and the abalone were allowed to exit at will. This procedure also provided protection from predators for the first 24 hours while the abalone became acclimatized to the environment.

At four experimental sites, 500 or 800 abalone of approximately 14 mm shell length were released per site. Growth and survival were monitored over twenty-four months and there was significantly slower growth through the summer compared to the winter months suggesting that the timing of the release is important to both survival and growth. Survival is reported in Table 1.

Table 1. Survival of Released Abalone

Sample Sites	**Released**	**April 1996**	**September 1996**	**March 1997**	**Survival to 6 months**
Site A	500	97	40	0	27.4%
Site B	500	117	70	19	39.2%
Site C	800	-	124	99	27.8%
Site D	800	-	145	60	25.6%
					Average 30%

The maximum mortality occurred during the first twenty-four hours after release and many remained in the transport devices for extended periods. Even at good sites there was little dispersal from the release area. Abalone appeared to seek out urchins for protection and were often found under the urchin spines. However, the presence of urchins did not appear to ensure a high survival rate since at one site no surviving abalone were found in March 1997. Factors affecting survival are complex, variable and inter-related, displaying a variable hierarchy of importance.

For ranching to be economically viable a survival rate of 5-10% for out-planted juveniles is required. Preliminary results suggested that, in certain circumstances, survival rates in excess of 30% could be obtained with seeded animals with particularly good survival being obtained when precautions are taken to reduce handling stress and at sites where sea urchins were present. Later work at similar sites, however, produced contrasting results and it was concluded that an extremely complex interplay between many different factors affected survival.

Of these, the presence of sea urchins was only important at certain sites, whilst, at other sites, the present of optimum-sized boulders seemed to replace that requirement. Overall, the size of seeded animals was the most important factor that influences survival, larger seed having better survival rates. Following the demonstration that, under certain circumstances, ranching could be economically feasible, genetic implications of this operation were investigated. Using mt-DNA markers, it was shown that, not only could animals from different geographic regions be shown to be genetically differentiated but, in addition, distinct genetic differences between naturally occurring and hatchery reared animals was also apparent.

QUESTIONS

Q: In Canada we use the precautionary approach - if we don't know the effect on the natural order of things, we don't proceed. How do you address this approach from a genetics point of view?
A: The precautionary approach is good if you have sufficient manpower to be able to find everything out in a timely fashion before you start. If that is the way we operated, not doing anything until we get all the information, nothing would get done.

Q: Why didn't you use animals from the same area?
A: We recognized there may be small genetic differences between hatchery reared animals and wild stocks. However, we thought that using hatchery animals would affect our results less than by using animals from a different area. Previously, there were "Genetic Zones" in Western Australia, then studies proved these zones were not necessary and the zone idea has since been abandoned.

Q: Could you change your hatchery spawning methods to mimic a wild situation with respect to male to female ratios and, therefore, reduce any genetic implications?
A: The hatchery at Port Nolloth has more than 200 broodstock and this number is generally considered adequate to maintain the required level of genetic diversity.

Q: What have the results been for the commercial scale operation?
A: About 2 million animals have been out-planted, but we don't yet know what the returns will be and, as I mentioned, returns can be highly variable.

Q: Is the commercial operation using condos?
A: The commercial operations have tried both condos and free-release by divers. When condos are used they are similar to the experimental units, but larger, housing up to 5000 juveniles that can enter and leave the condo at will. The use of condos reduces the handling stress compared to free-release.

Q: How much cheaper is ranching than land-based farming?
A: As yet, we don't know which will be the most economical. The land based grow-out costs much more but is it faster and there is a higher survival rate. A commercial operation is in the process of comparing the two methods right now. In the interim, they are claiming that the sea based ranching is the more viable option.

Q: Are you looking at ranching at sites where the abalone are naturally present?
A: Not really, there is total exclusion at the current experimental site, and that seems to be an important factor. At other sites where the abalone naturally occur, the habitat is similar to our experimental site but there are constant problems with poachers and also socio-economic issues that could prevent the success of the operation.

Q: Density dependant mortality is a big issue for juveniles less than 15mm, maybe this was a bottleneck with your out-planting?
A: I don't believe that food was the limiting factor. At the 15mm size, this species is eating macro-algae and there are very dense kelp beds at the planting sites.

Q: The survival data that you reported were 30% at 6 months, but the 55-60% survival had no time period. Have you looked at the survival over a longer period of time, for instance, the entire grow-out period?
A: The highest mortality was in the first 24 hours and mortality dropped off very sharply after that period. This species takes 4.0-4.5 years to harvest after planting at 15mm. The experiment hasn't been running for that long so we are not sure what the ultimate survival will be.

Q: Do you think the data indicating a higher survival rate for larger animals may be simply because it is easier to find them?
A: No, I don't think so. We suspect that the actual survival is better than what was reported because we did not find any dead shells.

Q: Have you compared the performance of animals to check if genetic variability has an impact on how well they perform?
Q: There are genetic differences between the east and west populations but there are also physiological differences. What we don't know is whether the physiological differences are due to acclimatizing or whether the genetic differences are causing performance variations.

Disussion: The genetic differences between the populations of abalone are the largest I have ever seen in a single species. To have that degree of genetic isolation, there must be physical differences caused by the different genetics. The different phenotype could also be due to hybridization effects. With a sample size of 25 animals, the hatchery stock would not be different from the western populations.
Yes, there is a huge variability within the east and west populations, but the differences between the farthest east and farthest west are due to not inter-breeding for a very long time.

OUT-PLANTING THE SEEDS OF SUCCESS: SEEDING HATCHERY-PRODUCED JUVENILE GREENLIP ABALONE, *HALIOTIS LAEVIGATA*, TO RESTORE NATURAL STOCKS [TITLE ONLY].

by

Dixon, C. D.[1], S. Huchette[1], R. Day[1], and S. A. Shepherd[2]

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[2]Aquatic Sciences, South Australian Resource and Development Institute, Australia

N.B. Full abstract and manuscript to be published elsewhere.

QUESTIONS

Q: Was there any natural recruitment to your reefs?
A: Very little, we found five abalone that had not been planted, these were Greenlip and a couple of other local species.

Q: What were the tags you used made of?
A: Plastic with gel superglue. The gel glue is very important to minimize tag loss and to not hurt the abalone.

Q: Was there much tag loss?
A: It depended on the tagging batch, the maximum loss of tags was 15-20% and we managed to recover some of them.

Q: Were the tags numbered or coloured?
A: The tags were both numbered and coloured. The different coloured tags each had a 1-letter and 3-digit code.

Q: What was the reason for the initial mortality? Perhaps the planting density was too high or more predators were attracted to the reefs with high numbers of animals?
A: That is questionable. We think the initial high mortality was due to the planting density, except at the Point Marsden site where all of the densities had very low survival. At the other sites, the abalone were at high densities were more exposed and may not have been able to find shelter, but we don't know if this attracted more predators or not.

Q: Do you attribute the abalone growth to diatom growth on the rocks?
A: No, growth observed was mainly due to consumption of drift algae.

Q: How would you reduce the initial mortality? Have you tried predator conditioning?
A: Juveniles conditioned with predators prior to out–planting tended to have lower survival than the control, possibly due to handling stress. Predator conditioning didn't affect the survival in a significant way.

Q: Do abalone eat live (standing) sea grass?
A: No. Only detached and drifting particles.

Q: How long did the tags last?
A: When they were attached properly, they lasted quite a long time (>15 months). The main problem with the tags is the foulant growth that accumulates. The tag must be scraped to be read and frequently this detached the tag from the abalone.

Q: Are you monitoring the abalone that have moved off the reefs?
A: We are starting to observe these animals; we want to see if they grow faster and why.

Q: With respect to the predator conditioning, when was it done?
A: It was one week pre-release.

Q: Would it make a difference if predator conditioning was carried out at more frequent intervals and for a longer period before release?
A: I don't think this would make a difference. Health and stress levels at the time of planting appeared to be much more important so we stressed them as little as possible. The brief experiment completed on predator conditioning actually showed lower survival in a predator-conditioned group than the control group.

REBUILDING CALIFORNIA ABALONE POPULATIONS [ABSTRACT].

by

Haaker[1], P. L., I. Taniguchi[1], J. Butler[2] and N. Wright[1]

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ABSTRACT

Haaker, P. L., I. Taniguchi, J. Butler, and N. Wright. 2003. Rebuilding California abalone populations [Abstract]. Can. Tech. Rep. Fish. Aquat. Sci. 2482: 103-106.

Since 1997, all seven California abalone species have been closed to commercial and recreational fishing south of San Francisco Bay. California abalone occur throughout the coastal marine environment from the intertidal zone to deep offshore reefs, presenting a challenge for the development of an abalone recovery plan. A successful plan needs to address the various characteristics of abalone and include an approach that can be applied as broadly as possible using available resources and a method for evaluation of progress.

Assessment of remaining abalone stocks is of immediate importance. Assessment goals have been established to address and prevent extinction of the abalone, to restore resource sustainability, and to rebuild resources to fishery sustainability levels. Assessment must include the identification of remnant populations, establishment of locations for further evaluation and determination of locations for enhancement.

The range of abalone is often specific, extensive, and with patterns of distribution. For each species, information on landings from fishing effort is accumulated into catch block areas which are used to determine the most extensive and the best habitat for abalone and used to determine research index sites. Population density is an essential element of the assessment; however, when numbers are low standard density surveys are uninformative. Free-form searches can yield more individuals than transect constrained surveys and data on individuals, such as size, can be collected.

Shell length (SL) is a population indicator, where the occurrence of a broad size range, even at low numbers, is evidence of reproduction and growth. Size surveys are conducted using three size categories, 0-100 mm SL, 100 mm SL to minimum legal size (MLS), and MLS to maximum size. Since the 0-100 mm SL category includes the cryptic population, which is

difficult and destructive to assess, it is only used for occasional determination of settlement. When a broad range of sizes is present, quantitative surveys are used to determine emergent abalone densities. A minimum viable population target size is an emergent population of 2,000 abalone per hectare, at all index locations. When an average of 6,600 abalone per hectare at 3/4 of the index locations is reached, a fishery could be considered.

Survey criteria and modifications should be made according to species characteristics. For example, surveying intertidal populations with a GPS can provide the position of each abalone. White abalone, currently surveyed using free form dives, could be surveyed using an ROV or submarine to provide geographic position. Multi-beam sonar sea floor maps are being generated by Department of Fish and Game and, together with data from a ROV, could be used to construct benthic habitat maps.

Abalone populations are at extremely low levels throughout southern California. Some remaining populations are so dispersed that successful natural reproduction is unlikely and enhancement may be the only remaining method of intervention. Enhancement techniques include aggregation of abalone, translocation of individuals from remote source populations, and out-planting of cultured juveniles and competent larvae. At the present, aggregation is seen as the only viable method of enhancement.

In abalone recovery, there are several challenges, which must be addressed as part of the recovery process. Some challenges must be considered before the recovery process can proceed. The presence of sea otters precludes a fishery of abalone and most other marine invertebrates. In the abalone recovery plan, any areas either currently or previously occupied by sea otters are excluded from assessment.

Disease has severely affected abalone stocks. The black abalone was virtually extirpated from southern California by withering syndrome. Withering syndrome is enhanced by warmer sea water temperatures, which is a concern for translocation projects. A parasitic sabellid worm, which causes shell growth disruption and deformity, was introduced into California aquaculture facilities and currently a prohibition exists on the out-planting of abalone from non-certified facilities.

Genetic questions need to be addressed, prior to translocation of abalone from different bio-geographic zones and using cultured animals for enhancement of natural populations.

Poaching of abalone is a serious problem in California. Recovery site criteria should include a low likelihood of illegal activity. Part of recovery is establishing large, dense populations and groups of individuals to facilitate reproduction. It is precisely those conditions that are good for poaching. Optimal locations would include remote islands, and mainland locations within limited access reserves.

Marine Protected Areas, MPAs, offer one of the best opportunities for abalone restoration activities. Recently, California established a number of MPAs at the Channel Islands National Marine Sanctuary and most include ongoing abalone study sites and appropriate abalone habitat.

Each abalone species has specific environmental requirements, which must be addressed to optimize successful recovery. Southern California is at the northern end of the range of pink, green, and white abalone, and the southern end of red abalone range. Red abalone growth and reproduction is depressed during warm water periods, but they can survive until temperatures decline. Pink and green abalone prefer warmer water which may allow their populations to extend farther northward with increasing sea water temperatures. Other factors are complicated by environmental effects. If sea water temperatures increase farther north, withering syndrome may become infectious in northern populations.

Our major challenge in rebuilding abalone stocks is to return at least part of the abalone population to a natural situation, where bio-diversity and natural selection can be effective.

QUESTIONS

Q: How do you think we fare in British Columbia in terms of endangerment for the Pinto abalone?
A: The situation here seems to be better in BC; in California we are not as far along in the conservation efforts for white abalone as we are with our other species. The situation in California is different as there is a much larger diving population. In British Columbia, there are more remote areas where people can't get to as easily and the natives are more protective of the resource.

Q: Do you have community projects involved in your conservation measures?
A: The recreational divers were heavily involved instituting the initial fishery closures. Some dive clubs and commercial divers realized that abalone were in decline and attempted to out-plant abalone seed using various methods. It was the recreational divers who exerted considerable influence in getting the fishery closed.

Q: Are there still remnant abalone populations where sea otters are present?
A: Yes, central California has very high numbers of red and black abalone in crevice habitat, but large abalone are rarely seen. The situation is different with the other species. It is also difficult to tell if the base cryptic population is sufficient to maintain the population as a whole.

Q: What is the baseline, "ideal" population level that you refer to?
A: The base population numbers that I refer to are the abalone densities prior to 1950, when there were no sea otters in the area.

Q: I think that USA and Canada have the same issues, in regards to abalone, how do you manage the sea urchin fishery when abalone are endangered?
A: Listing an animal as endangered does not require critical habitat to be designated, so we don't have to consider associated animals like sea urchins as part of the management plan. However, because sea urchin and abalone have many common characteristics, including similar habitat and food, we are certainly keeping sea urchins in mind.

Q: Do you put closure zones around areas of white abalone abundance?

A: No, the areas of abundance are mostly deep water so poaching is not really a problem with this species. In order to close the area we have to list critical habitat, which involves giving a detailed description and location. We feel this would draw the poachers to the area since this information is public.

Discussion: With respect to the California sea otter populations, white abalone are probably in the best situation because they are a deep water species. The other abalone species are found in shallower water and within the otter's diving range. Pink and red abalone are likely the only two abalone species to have a future fishery and that would probably be restricted to a skin diving fishery.

SUMMARIES OF BREAKOUT GROUPS

On day three of the workshop, the participants were divided into five groups. Each group was given a component of an abalone rehabilitation program appropriate for northern abalone management in British Columbia. The groups were as follows.

Group 1. Hatchery Rearing

Group 2. Out-planting and Restocking Methods

Group 3. Wild Stock Manipulation Methods

Group 4. Monitoring Tools and Evaluation Performance Indicators I - Survey Methods and Tagging

Group 5. Monitoring Tools and Evaluation Performance Indicators II - Modelling, Strategies and Challenges for Monitoring

Each group was asked to determine the constraints to their component of the rehabilitation program that results in an inability of this component to provide fully to the rehabilitation program in British Columbia. The groups were also asked to suggest solutions, wherever possible, to alleviate these constraints. Each group presented their conclusions to the workshop participants and a discussion period followed each presentation. A summary of the presentations follows.

GROUP 1. HATCHERY REARING

Participants:

Chris Pearce
John Rosser
Guy White
Rodney Robers

Dawn Renfrew
Bill Heath
Carolyn Friedman
Ruth Withler

The development of hatchery techniques for production of abalone larvae and/or juveniles for stock rehabilitation and the successful integration of cultured animals into the northern abalone rehabilitation plan require the following components.

Fisheries and Oceans Canada Responsibilities

1. Clarify the role of government in abalone stock rebuilding

2. Provide financial support to the commercial abalone culture industry as it is not the responsibility of private companies to cover the cost of stock recovery programs
3. Provide government support and funding for long term research and stock rebuilding projects
4. Develop long-term partnerships and contracts between government and industry to provide access to broodstock
5. Determine a policy on sea-ranching of hatchery reared abalone around which abalone culture can be utilized by rehabilitation management plans

Broodstock Collection, Retention, and Return Priorities

1. Guaranteed access to broodstock over the long-term for hatcheries
2. Methods of tracking returned abalone to natural environment
3. Research into broodstock and offspring health and viability

Post Larval Research Priorities

1. Larval settlement density
2. Increasing metamorphic success
3. Early nutrition
4. Specific strains of diatoms and their affect on larvae with respect to nutrition, settlement, and quality
5. Use of prepared diets
6. Grazing-resistant algae

Out-planting Research Required

1. Timing/season/life stage most successful
2. Larval criteria
3. Juveniles - considerations of higher cost Vs survival
4. Use information from Session 2, and other rehabilitation programs
5. Conditioning, acclimatization with predators, habitat, food
6. Methodology for transport

GROUP 2. OUT-PLANTING AND RESTOCKING METHODS

Participants:

Laurie Convey
Tom McCormick
Sylvain Huchette
Susan Bower
Cate Henderson
Anne Stewart
James Hamly
Pele Agerup

Priorities - for the development of successful out-planting and restocking methods for stock rehabilitation using hatchery-reared abalone the following priorities must be addressed as soon as possible.

1. Determine rehabilitation goals in terms of target numbers of abalone stock
2. Determine research methodology and management plans
3. Hatchery projects need financial support as stock enhancement requirements are different from commercial venture essentials

Goals - an out-planting and restocking strategy should include the following.

1. Qualitative assessment criteria
2. Quantitative assessment criteria (the ideal numbers)
3. Target densities, specified by area
4. Data collection plan over the long term, (it takes 3-4 years for abalone to be large enough to measure)
5. Long term goals - 5-10 years to determine success

A successful abalone out-planting and restocking strategy will need to include the following.

Genetics - spawning techniques to avoid loss of genetic diversity, tools and resources for continued genetic monitoring of stocks

Quality-Health Research

1. Disease screening to ensure fitness of hatchery-raised abalone for planting in the wild
2. Shell colour to ensure that the hatchery-raised abalone are the same colour as wild
3. Naivety or predator conditioning
4. Cryptic behaviour information
5. Conditioning, if required

Size and Age of Out-planting

1. Determine method to evaluate success for larvae
2. Economic evaluation to determine optimum size and economic viability of this option

Out-planting Methodology

1. Ensure adequate replicates and scientific methods used
2. Always have controls
3. All studies according to scientific research principles

Release Habitat Research

1. Protection from predation
2. Site criteria for protection from poaching
3. Suitable size to be released
4. Determine appropriate season in regards to growth, food availability-both at planting and over time to reduce suspected bottlenecks in the food availability
5. Ideal physical habitat criteria, including cryptic habitat availability, rugosity and geographic location

Transplant Stress

1. Explore the use of release modules
2. Determine how to reduce initial mortality through reduced handling, using tubes for transport, providing protect for first 6 hours after release

Out-planting Density - determine method to accurately measure density over time

Depth – all parameters require research, i.e., 6-9 meters, directional movement

GROUP 3. WILD STOCK MANIPULATION METHODS

Participants:

Lynne Lee	Peter Cook
Joanne Lessard	James Mortimer
Doug Brouwer	Tammy Norgard
Heather Holmes	

The following were determined to be critical issues for the use of wild abalone manipulations for future stock enhancement.

Determination of Appropriate Stocking Densities

1. For Northern abalone and for BC oceanographic conditions
2. Use data and established information on minimum stocking densities from Australia and New Zealand for modelling in BC
3. Take into account site conditions and evidence of recruitment failure
4. Define recruitment success
5. Determine critical broodstock densities for specific conditions

Larval Dispersal Research

1. Determine the source(s) of current successful recruitment
2. Determination of larval period in the wild
3. Coastal oceanographic information
4. Implication of larval dispersal on genetics

Site Selection Criteria

1. Assume ongoing monitoring is required
2. Definition of good abalone habitat characteristics
3. Dissolved oxygen criteria, minimum 85% saturation

Timing of Broodstock Translocation - to reduce dispersal post-translocation

Handling Techniques – to reduce stress and mortality

The following risks in undertaking a program of translocation of abalone are to be considered.

1. Disease transfer
2. Genetics – over the long term
3. Survivorship of transplants
4. Poaching

The following are priority issues for a continued program for abalone translocations.

1. Critical density relating to environmental conditions, including definition of critical density for Northern abalone specifically, long term monitoring over large areas and the short term need to proceed with the "best guess" for density.

2. Larval dispersal information is required through oceanographic research, larval collectors, plankton tows, monitoring time of natural spawning to collect larva, family specific analysis of spawners, juveniles and larva to determine larval dispersal.

3. Site selection information is required from historical distribution, biotic and abiotic habitat preferences from surveys of current populations, oceanography to determine the probability of seeding source sites, such as south end of Vancouver Island, Haida Gwaii/Queen Charlotte Islands. All sites must be accessible year-round.

4. Stewardship and Coastwatch potential for ongoing surveillance and reporting of illegal activities should be integrated into the recovery program.

5. Compilation and analysis of all existing northern abalone data may start to answer some questions and must continue.

6. A co-ordinated coast-wide effort in future research is required.

GROUP 4. MONITORING TOOLS AND EVALUATION PERFORMANCE INDICATORS I - SURVEY METHODS AND TAGGING

Participants:

Ian Perry	James Pegg
Peter Haaker	Tom Tomascik
Joel Harding	Bart DeFreitas
Barbara Lucas	

Priorities - The determination of the appropriate life stages to survey and at what stages recruitment efforts are best monitored are the priorities for the development of abalone survey methodologies. Both larval and juvenile abalone density surveys have potential problems.

- Larvae – Plankton tows would yield some very early life stage data but there may be problems in identification abalone larvae. Traditional methods of surveying plankton involve a large amount of material and much time to analyze. Early results are required to project retain funding.

- Juvenile Abalone – This information is easier to obtain but not without some problems since juveniles are still cryptic and hidden. A system for forcing movement, i.e., using starfish cocktails and tagging would be useful.

Habitat Criteria - The determination of appropriate habitat criteria, biotic and abiotic, is essential, including general and specific features, sediment types/distributions, detailed bathymetry. Consistent methods to evaluate habitat in relation to abalone abundance are required.

Site Surveys - Geo-referencing all data is required along with general location information and specific distributions of individuals/groups of abalone. Referencing locations underwater can be accomplished with GPS, it is important to know the site as the animals could be 5m apart vertically but only 0.5m apart horizontally.

Dive Surveys - The limitations of using diving surveys, especially the cost, were recognized. Methods of surveying without divers should be examined, such as beach walks, counting abalone shells to indicate significant sites, and compiling of this information into a usable database.

Survey Types – The different types of survey should be considered, i.e., site specific versus broad-scale surveys. There has been some dissatisfaction with Breen method, more research is required to refine this method. Replicate index sites and possible condo programs need to be explored. Low technical (simple) methods may be appropriate for broad-scale surveys with comparisons of the efficiency of both survey approaches in good and poor abalone areas.

Tagging – A method of identification is essential to distinguish wild abalone from hatchery stock and for ongoing stock assessment. The use of "genetic tags" to identify hatchery out-plants needs research. Tag attachment methodology is required to apply tags underwater and ensure tags are retained.

Scales of Time - Acoustic tagging is required to understand daily/seasonal movements (spatial scale). There is a need to resample often and to determine if the movements are a function of age, food availability etc.

GROUP 5. MONITORING TOOLS AND EVALUATION PERFORMANCE INDICATORS II - MODELLING, STRATEGIES AND CHALLENGES FOR MONITORING

Participants:

Don Rothaus
Wayne Hajas
Jim Boutillier
Bryan Jubinville
Shannon Gregg
Glen Jamieson

The group stated that they were unable to determine appropriate methodologies for testing rebuilding strategies; however, they did determine that the following further work in stock recruitment relationships is required.

1. Design various studies to test appropriate densities needed to generate desired recruitment levels
2. Sensitivity modelling is critical
3. Determine which variables are critical - recruitment, natural mortality, fishing mortality (illegal and other), oceanic conditions

Challenges for Monitoring and Enforcement

1. Officers must be trained in identification of abalone. Because of low population numbers, they have often only seen shells or book descriptions.
2. Education of officers on enhancement sites is important.
3. Protocols need to be determined for abalone enforcement, including market place, field work and public contacts.
4. Greater deterrence for convicted illegal harvesters is required.
5. The designated 100 fishery officers are not adequate for the BC coast and there is a need for help from upland owners and communities. Recognition of ongoing essential role of communities for protection of studies and assessment, and continued and increased participation of First Nations is required.
6. If appropriate, resurrect guardian stations along the coast at critical sites.
7. Restrict or eliminate sports and commercial diving at priority study sites.
8. Restrictions and closures need to be enforceable.
9. Educate people that live around the study areas that "if you see anybody diving here, report it because it is illegal".
10. Local initiatives are to be supported, however, there may be a need to create or develop an International Law Enforcement network to address enforcement issues, trends, 10 most wanted list etc.

SUMMARY AND CLOSE

WORKSHOP SUMMARY

by

A. Campbell

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INTRODUCTION

The purpose of this paper is to summarize the salient points from the formal presentations and the group discussions made at the Workshop on Rebuilding Techniques for Abalone in British Columbia (BC) which was held in Nanaimo, BC, Canada, 14-16 January 2003. The workshop brought together individuals from diverse groups to consider methods to be used in achieving the common goal of rebuilding depleted abalone populations. In particular, the workshop was focused on refining the rebuilding program for northern abalone (*Haliotis kamtschatkana*) in BC, a species which is listed as 'threatened' ("likely to become endangered if limiting factors are not reversed") by the Committee on the Status for Endangered Wildlife in Canada (COSEWIC). The workshop highlighted the progress that has been made in implementing a rebuilding strategy developed at the last workshop held in Nanaimo in 1999 (Campbell 2000, Toole et al. 2002) and again emphasised that success will continue to require a co-operative effort. Although the workshop presentations and discussions indicated we are still in the learning phase on the road to developing effective and cost efficient methods for rehabilitating depleted abalone populations, the workshop provided useful information and direction for the future of the abalone rebuilding efforts in BC.

STEWARDSHIP PROJECTS

Three papers presented from the Haida, Kitasoo, and Bamfield Huu ay aht groups indicated that the Habitat Stewardship Program, funded by the Government of Canada and administered by Environment Canada, has encouraged community involvement in many aspects of abalone recovery (Harding 2003, Jones et al. 2003, Stewart 2003). Activities have included: community outreach and education, ranging from holding workshops, preparing information brochures and posters, local television and radio programs, creating web sites and training on biology and traditional knowledge; creating a Coast Watch Program; dive activities and training community divers to test rebuilding approaches and monitor abalone populations; and building a hatchery to raise abalone for out-planting and research that has fostered a sense of community ownership. Collaborative partnerships have been developing between different local interest groups and between DFO, Parks Canada, universities, and coastal communities. Jones et al. (2003) cautioned that although the results have been positive after three years of the program, the challenge will be to keep the community commitment to stewardship over a long time period.

particularly without favourable indications that abalone numbers are rebuilding which would allow consideration for harvest by First Nations. Several references were made throughout the workshop about sea otters and that the presence of sea otters in some areas may not be compatible with recovery efforts on abalone. There is much potential for stewardship projects in the future, especially as there are many small coastal communities in the large mostly uninhabited coastline of BC.

ENFORCEMENT ISSUES

In the paper presented on enforcement, Jubinville (2003) emphasised that reports from the public on poaching activity had declined in recent years, however this could not be attributed to an actual reduction in poaching activities. As enforcement officers rely on the public's assistance, the lack of reports was a concern. Discussions centred on how best to improve enforcement. Co-operation amongst local communities, First Nations, the general public and enforcement agencies to support the reduction in illegal harvest of abalone is needed. Fisheries officers need to be trained in identification of northern abalone from other legally obtained abalone species, and educated on the purpose and location of enhancement areas.

From an international perspective, poaching of wild abalone throughout the world continues to be a major problem and is becoming increasingly efficient, effective and most likely conducted by organised crime syndicates. An "International Law Enforcement" network is required to co-ordinate co-operation between countries to reduce the black market of trafficking illegally caught wild abalone throughout the world.

AQUACULTURE

Two papers were presented on the culture of abalone. Pearce et al. (2003) summarised the development of the abalone aquaculture industry in BC, which has been at the infancy stage but is progressing and benefiting from the advancing global pool of knowledge in abalone aquaculture. McCormick and Brogan (2003) showed that providing optimal quality food accelerated the maturation process of white abalone assisting hatcheries to increase the frequency of spawning and the rapid production of broodstock.

Discussions centred on broodstock collection, quality and maintenance and production of viable offspring. Use of appropriate nutrition (through prepared diets, algae, and diatom strains) and algal densities were considered important in producing optimal abalone larval and juvenile growth and survival. The green alga, *Ulvella lens*, is being used by some hatcheries to provide a food source that resists being completely grazed by small juvenile abalone. Additional aspects of aquaculture were also touched on in other presentations/discussions and summarised below.

DISEASES

Bower (2003) reviewed recent discoveries on diseases of abalone and discussed the screening for and prevention of disease, which would be important not only for good husbandry in the aquaculture facilities but also in out-planting hatchery raised abalone into the wild.

Acquisition of more data from examination of abalone will increase capacity to assess abalone health in the future.

GENETICS

Withler et al. (2003) showed that northern abalone, *Haliotis kamtschatkana*, is genetically similar throughout BC and Alaska. Withler et al. (2003) also emphasised the need for vigilance to ensure that hatchery-spawning techniques avoid narrowing of the genetic pool especially where hatchery-raised progeny will be outplanted into the wild to rebuild the wild population. Discussion included the need for continued genetic work for enforcement and ongoing support for research and the rebuilding program. The challenges of being able to maintain genetic diversity for the purposes of wild stock enhancement over genetic selection (e.g., for faster growth) by the aquaculturist were also discussed.

REHABILITATION METHODS

Four presentations examined stock rebuilding methods in New Zealand (Roberts 2003), South Africa (Cook 2003), Australia (C. D. Dixon et al. personal communication, University of Melbourne) and California (Haaker et al. 2003). Roberts (2003) reviewed rebuilding methods in New Zealand, where a variety of hatchery raised early abalone stages (eggs, larvae, post larvae and juveniles) were being released into the wild. Roberts (2003) emphasised the importance of suitable recipient habitat substrate requirements for the success of reseeding and cost-effective survival. Cook (2003) reviewed the ocean ranching project in South Africa showing that outplanting of cultured abalone to the wild can be successful. Outplanting of both larval and juvenile cultured abalone has been attempted in Australia, though research is still being conducted to develop transplanting techniques. C. D. Dixon et al. (personal communication, University of Melbourne) reported on carefully planned and executed experiments to increase the survival of outplanted juvenile abalone into the wild of Australia. Haaker et al. (2003) indicated that most of the abalone fisheries had been closed in California due to stock declines and that Marine Protected Areas (MPAs) were being considered as an important restoration activity.

Discussions on rebuilding abalone populations by outplanting and restocking with hatchery raised abalone, and by wild stock manipulation methods follow. Reducing risks common to these rebuilding methods should include monitoring diseases, maintaining genetic diversity, increasing transplant survivorship through reduced handling stress and appropriate site selection to reduce the possibility of poaching.

OUTPLANTING

Development of outplanting methods through research and the integration of these methods and goals for target numbers into management plans are important. Research into outplanting different stages and sizes of hatchery raised abalone (larvae, juveniles) requires biological and economic evaluation. Preconditioning abalone to predators prior to release may be important to reduce the naivety and increase survival rates of hatchery-raised abalone in the wild. The appropriate release size and density of abalone will depend on the local situation and a balance between cost of production and the requirement for a level of survival and retention of abalone within the recovery area. Releasing pre-settlement larval abalone, although the cheapest to produce, may be the most difficult to monitor and ensure survival and retention in an area.

Testing of outplanting methods should follow scientific principles, which include adequate experimental design (replication of treatments including controls).

Site selection prior to release is critical for stock enhancement. Choice of recipient habitats may not always be predictable since there are a large number of interacting variables, which influence the survival of outplanted abalone. Habitats that provide high rugosity or crevices to reduce predation pressure and plenty of appropriate food types are some factors important in ensuring good juvenile growth and survival. The timing of release (night or day and season) also may be important in terms of predation and food supply.

Small holding containers/modules for juveniles have been shown to be helpful in reducing handling and transportation stress and allow abalone to acclimatise to the local environment before venturing out into the wild.

WILD STOCK MANIPULATION

Wild abalone stock manipulations have been suggested as a way to increase abalone populations. These manipulations may include translocating abalone for a variety of reasons, such as (a) increasing growth rates in optimal habitats, (b) increasing abalone densities to increase reproductive potential, and (c) re-establishing abalone in areas where they have disappeared. There needs to be an explicit framework to guide long-term decisions, to evaluate methods on a small scale prior to large scale applications thereby reducing uncertainties and conflicting objectives through a risk averse examination of the life history, ecological, economic and social issues.

We have little information on northern abalone stock and recruitment relationships. Examining general and local hydrographic currents in BC would help in understanding the relationship between sources of broodstock and the resulting sinks where the larvae might settle. Research is required on determining critical broodstock densities under local conditions and how this would translate into successful recruitment. Selecting good habitat for abalone broodstock and juveniles, as well as, the timing of broodstock translocation for concentrating abalone to increase reproductive success were considered important.

MONITORING POPULATIONS

Assessment of abalone populations in terms of density and patterns of distribution in relation to habitat types on a variety of spatial and temporal scales was discussed in several papers (Haaker et al. 2003, Mortimor et al. 2003, Rothaus and Friedman 2003, Tomascik and Holmes 2003). DeFreitas (2003) introduced a modified artificial habitat (condos) as a method to measure recruitment in juvenile abalone. Although condos show promise as a convenient monitoring tool, there is need to calibrate the indices produced in relation to natural recruitment and the surrounding substrate and habitat types. Campbell et al. (2003) compared the potential reproduction capacity of abalone from "surf" or poor areas where growth is stunted to areas with good habitat.

Discussions focused on survey methods. The choice and design of survey method will depend on the objectives of the study. The frequency of sampling in terms of time and spatial scales need to be considered in survey design. New methods need to be developed to efficiently survey aggregated abalone populations. Survey methods need to be developed to efficiently record and quantify potentially "good" and "poor" habitats for abalone in coastal BC for potential rebuilding areas. Methods [e.g., remote operated vehicles (ROVs), night/day dive surveys] to qualitatively or quantitatively record habitat types and abalone abundance need to be explored further with standardisation and calibration of appropriate methods for each type of habitat. Electronic geo-referencing (GPS) of habitat and abalone abundance data collection during surveys should become routine along with the recording of ancillary physical information such as slope and substrate for more accurate positioning underwater.

Tagging methods are important for (a) ongoing assessments, (b) distinguishing hatchery reared outplanted abalone from wild abalone, and (c) documenting growth, survival and movement behaviour (day/night, seasonal) of abalone in different habitats. There are a variety of tagging methods (e.g., external plastic/metal tags, acoustic, genetic) that need to be evaluated for tag retention longevity, logistic efficiency of application and recovery.

Monitoring the success of pilot experimental methods and or rebuilding actions will require a number of tools (survey techniques, methods for juvenile sampling, tags, computer statistics/dynamic simulation models) to determine if the goals are achieved. Spatial and temporal scales, demographic (different abalone life stages, e.g., larvae, juvenile, adults), environmental (habitat) and ecological variability may influence not only the eventual target abalone population size but the correct choice of the monitoring tool and performance indicator. Monitoring of the rebuilding efforts needs to be continually evaluated to determine if the intermediate objectives and long term goals are being achieved. Periodic assessment not only of the abalone stocks but also of community participation throughout BC is needed to indicate progress in rebuilding the abalone population.

ACKNOWLEDGEMENTS

I thank all the workshop participants for their enthusiastic participation and Laurie Convey and Linda Hiemstra for providing helpful comments on this summary.

REFERENCES

Bower, S. M. 2003. Update on emerging abalone diseases and techniques for health assessment. J. Shellfish Res. 22 (3) (in press).

Campbell, A. (Editor). 2000. Workshop on rebuilding abalone stocks in British Columbia. Can. Spec. Publ. Fish. Aquat. Sci. 130: 158 p.

Campbell, A., J. Lessard, and G. S. Jamieson. 2003. Fecundity and seasonal reproduction of northern abalone, *Haliotis kamtschatkana*, in Barkley Sound, Canada. J. Shellfish Res. 22 (3) (in press).

Cook, P. 2003. A review of abalone enhancement and rehabilitation in South Africa [Abstract]. Can. Tech. Rep. Fish. Aquat. Sci. 2482: 97-100.

DeFreitas, B. 2003. Estimating juvenile northern Abalone, *Haliotis kamtschatkana*, abundance using artificial habitats. J. Shellfish Res. 22 (3) (in press).

Haaker, P. L., I. Taniguchi, J. Butler, and N. Wright. 2003. Rebuilding California abalone populations [Abstract]. Can. Tech. Rep. Fish. Aquat. Sci. 2482: 103-106.

Harding, J. 2003. The Kitasoo abalone stewardship project: small project, big hopes [Abstract]. Can. Tech. Rep. Fish. Aquat. Sci. 2482: 20-22.

Jones. R., B. DeFreitas, N. Sloan, L. Lee, K. von Boetticher, and G. Martin. 2003. Abalone stewardship in Haida Gwaii: forging a long-term commitment. Can. Tech. Rep. Fish. Aquat. Sci. 2482: 5-19.

Jubinville, B. 2003. Have we got problems [Abstract]. Can. Tech. Rep. Fish. Aquat. Sci. 2482: 26-27.

McCormick, T. B. and J. L Brogan. 2003. Early reproduction in hatchery-raised white abalone, *Haliotis sorenseni*, Bartsch, 1940. J. Shellfish Res. 22 (3) (in press).

Mortimor, J. P., C. R. Henderson, and G. R. D. Elliott. 2003. Night and day surveys of a northern abalone, *Haliotis kamtschatkana*, population, in Eagle Bay, British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 2482: 49-65.

Pearce, C. M., P. Ågerup, A. Alabi, D. Renfrew, J. Rosser, G. Whyte, and F. Yuan. 2003. Recent progress in hatchery production of pinto abalone, *Haliotis kamtschatkana*, in British Columbia, Canada. Can. Tech. Rep. Fish. Aquat. Sci. 2482: 29-44.

Roberts, R. 2003. A perspective from New Zealand on abalone stock enhancement, with emphasis on early life history. Can. Tech. Rep. Fish. Aquat. Sci. 2482: 77-96.

Rothaus, D. P. and C. S. Friedman. 2003. Trends in pinto abalone (*Haliotis kamtschatkana*) abundance in the San Juan Islands and management of abalone in Washington State [Abstract]. Can. Tech. Rep. Fish. Aquat. Sci. 2482: 71-73.

Stewart, A. 2003. Absolutely abalone: Habitat stewardship programme for the pinto abalone on the west coast of Vancouver Island [abstract]. Can. Tech. Rep. Fish. Aquat. Sci. 2482: 23-24.

Tomascik, T. and H. Holmes. 2003. Distribution and abundance of *Haliotis kamtschatkana* in relation to habitat, competitors and predators in the Broken Group Islands, Pacific Rim National Park Reserve of Canada. J. Shellfish Res. 22 (3) (in press).

Toole, J., B. Adkins, E. Bornhold, J. Boutillier, G. Caine, A. Campbell, A. Castledine, L. Convey, C. Cote, P. Coulson, T. Down, K. Francis, H. Gill, R. Harbo, H. Holmes, B. Jubinville, D. Lawseth, B. G. Lucas, A. Morgan, G. Parker & J. Rogers. 2002. National Recovery Strategy for the Northern Abalone (*Haliotis kamtschatkana*) in British Columbia. Fisheries and Oceans Canada. (http://www-comm.pac.dfo-mpo.gc.ca/pages/consultations/fisheriesmgmt/abalone/AbaloneRecovStrategy_e.htm). 22 p.

Withler, R. E., A. Campbell, D. Brouwer, S. Li, K. J. Supernault, and K. M. Miller. 2003. Implications of high levels of genetic diversity and weak population structure for the rebuilding of northern abalone populations in British Columbia, Canada. J. Shellfish Res. 22 (3) (in press).

CLOSING REMARKS

by

E. A. Perry

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I would like to open my remarks by reflecting on the state of Canada's natural environment. The Annual Report to Parliament by the Treasury Board of Canada, "Canada's Performance 2002", provides a snapshot of how well the country is doing with respect to some key economic, human health, social and environmental criteria. The report concludes that over the past 10 to 15 years Canada's air quality and water quality have generally improved. However, it also concludes that biodiversity has decreased. The bottom line is that we are not succeeding in our efforts to conserve the 71,500 known species of animals, plants and other organisms in Canada.

The Species at Risk Act, designed to maintain biodiversity in Canada, is expected to be Proclaimed in June 2003. As scientists and resource managers we can anticipate that the Act will increase demands on our time and resources, perhaps with inadequate new support and at the cost of some of the things that we now do and consider high priority. It is my view, however, that the legislation will help us to do a better job of protecting biological diversity in Canada. Most importantly it will strengthen our resolve to manage species in a manner to maintain or improve stock status, thus avoiding listing by COSEWIC. The message that it is better to prevent problems than to try to fix things after they are broken will be progressively re-enforced as we respond to an accumulating number of listed species. The Act will also ensure that decisions on the management of species of concern, and the human activities that affect them, are made in a transparent and inclusive framework, a framework quite different than we have sometimes seen in the past.

The fundamental requirements for managing and conserving biodiversity are knowledge, innovative and adaptive approaches, and partnerships with sectors of society that have an impact, so solutions are lasting. A clear conclusion from this workshop is that major strides are being made on all fronts for northern abalone. Knowledge is being improved and shared at the local and international level. All avenues for rebuilding the abalone, from public awareness, to enforcement, to enhancement are being examined and implemented and lessons learned are being applied elsewhere. And the programs described in the stewardship segment of the workshop illustrate an incredible networking of individuals and organizations with the objective of rebuilding abalone stocks in British Columbia.

I believe your willingness to share information and ideas, and your commitment to making things happen, greatly improves the odds that we will succeed in rebuilding northern abalone populations. The results of this workshop will provide guidance to future endeavours on research efforts and rehabilitation projects. Your advice will provide direction as we further develop and implement the action plan for abalone rebuilding. It is heartening to see such diverse interest and participation, including coastal communities, First Nations, environmental organizations, other countries, industry, university, and federal and provincial government agencies. So, on behalf of Fisheries and Oceans Canada, and northern abalone, I would like to thank you all for coming to Nanaimo and participating in this workshop. It trust it was a rewarding experience for everyone, and that you have forged relationships that will be of value in the years to come.

I would also like to thanks members of the committee who have worked hard to help organize and deliver the workshop: Linda Hiemstra, who facilitated the workshop, Laurie Convey, Sharon Humphreys and Shannon Gregg. I would expressly like to thank Dr. Alan Campbell for his dedication and energy in his work on abalone over the past 15 years, and for organizing and leading this workshop. Finally, I hope you will all have a safe journey home.

APPENDIX 1. PROGRAM AGENDA

DAY 1. TUESDAY JANUARY 14, 2003

Welcome and Opening Remarks

Linda Hiemstra, Workshop Facilitator

Introduction and Overview

Serge Labonté, Director General, Fisheries & Biodiversity Science Branch, Fisheries and Oceans Canada

Session 1. Status of Rebuilding Projects

Chair: Laurie Convey, Fisheries and Oceans Canada
Russ Jones*, B. DeFreitas, N. Sloan, L. Lee, K. von Boetticher, and G. Martin, Abalone stewardship in Haida Gwaii: forging a long-term commitment
Joel Harding: The Kitasoo abalone stewardship project.
E.A. (Anne) Stewart: Absolutely abalone: habitat stewardship programme for the pinto abalone on the west coast of Vancouver Island.
J. P. Mortimor, R.D. Elliott and C. (Catie) R. Henderson*: Survey of northern abalone, *Haliotis kamtschatkana*, populations in Eagle Bay, Barkley Sound, British Columbia, February/ March 2002.
Bryan Jubinville: Have we got problems.
Discussion

Session 2. Aquaculture

Chair: Bill Heath, Ministry of Agriculture, Food & Fisheries
Christopher M. Pearce*, P. Agerup, A. Alabi, D. Renfrew, J. Rosser, G. Whyte, F. Yuan: Recent progress in hatchery production of pinto abalone, *Haliotis kamtschatkana* Jonas, in British Columbia, Canada.
Susan Bower: Update on emerging abalone diseases and techniques for health assessment.
Peter Cook: A Review of Abalone Enhancement and Rehabilitation in South Africa.
Rodney Roberts: A perspective from New Zealand on abalone stock enhancement, with emphasis on early life history.
Discussion

* Speaker

DAY 2. WEDNESDAY JANUARY 15, 2003

Opening Remarks

Linda Hiemstra, Workshop Facilitator

Session 3. Field Research

Chair: Carolyn Friedman, University of Washington

Heather Holmes and Tomas Tomascik*: The distribution and abundance of northern abalone (*Haliotis kamtschatkana*) in the Broken Group Islands, Pacific Rim National Park Reserve of Canada.

Alan Campbell*, J. Lessard, and G. S. Jamieson: Fecundity and seasonal reproduction of northern abalone, *Haliotis kamtschatkana*, in Barkley Sound, Canada.

Bart DeFreitas: Estimating juvenile northern abalone, *Haliotis kamtschatkana*, abundance using artificial habitats.

Don P. Rothaus* and C. S. Friedman: Trends in Pinto Abalone (*Haliotis kamtschatkana*) Abundance in the San Juan Islands and management of abalone in Washington State.

Ruth E. Withler*, A. Campbell, D. Brouwer, S. Li, K. J. Supernault, D. Brouwer and K. M. Miller: Implications of high levels of genetic diversity and weak population structure for the rebuilding of northern abalone in British Columbia.

Discussion

Session 4. Rehabilitation Methods

Chair: Heather Holmes, Parks Canada

Tom B. McCormick* and J.L. Brogan: Early reproduction in hatchery-raised white abalone, *Haliotis sorenseni*, Bartsch, 1940.

C. D. Dixon, Sylvain Huchette*, R. W. Day and S. A. Shepherd: Outplanting the seeds of success: Seeding hatchery-produced juvenile greenlip abalone, *Haliotis laevigata*, to restore natural stocks.

Peter L. Haaker*, I. Taniguchi, J. Butler and N. Wright: Rebuilding California abalone populations.

Discussion

* Speaker

DAY 3. THURSDAY JANUARY 16, 2003

Opening Remarks

Linda Hiemstra, Workshop Facilitator

Session 5. Future Directions *Self-facilitated Groups*

1. Hatchery Rearing
2. Out-planting and Restocking Methods
3. Wild Stock Manipulation Methods
4. Monitoring Tools and Evaluation Performance Indicators I – Survey Methods and Tagging
5. Monitoring Tools and Evaluation Performance Indicators II – Modelling, Strategies and Challenges for Monitoring

Group Summaries and Plenary Discussions
Chair: Linda Hiemstra

Workshop Summary

Alan Campbell, Fisheries and Oceans Canada

Closing Remarks

Ted Perry, Fisheries and Oceans Canada